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NATURAL PHENOMENA HAZARDS (NPH) DESIGN CRITERIA AND OTHER CHARACTERIZATION INFORMATION FOR THE MIXED OXIDE (MOX) FUEL FABRICATION FACILITY AT SAVANNAH RIVER SITE (U)

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

SRS
savannah river site ™

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DISCLAIMER

Project: Mixed Oxide (MOX) Fuel Fabrication Facility

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Title: Natural Phenomena Hazards (NPH) Design Criteria and Other Characterization Information for the Mixed Oxide (MOX) Fuel Fabrication Facility at Savannah River Site (U)

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SUMMARY

This report was developed for Duke/Cogema/Stone & Webster (DCS) in accordance with Work Task Agreement (WTA) 023, dated June 23, 2000. The objective was to document the existing Savannah River Site (SRS) regional and local geologic conditions and Natural Phenomena Hazards (NPH) Criteria and provide other characterization information that is applicable to the ongoing site-specific studies for the Mixed Oxide (MOX) Fuel Fabrication Facility.

This report includes technical data and results from previous studies related to the Geological, Geotechnical, Seismological and Natural Phenomena Hazards (NPH) Information for the MOX Facility (including wind and rain data). The report is a comprehensive compilation applicable to the general Savannah River Site area, developed by both the original contractor, the DuPont Company and by the current plant operator, Westinghouse Savannah River Company, over the full plant lifetime period (1950 – 2000). Major portions of this report were extracted and consolidated from the following primary reference document:

Savannah River Site, Generic Safety Analysis Report (G-SAR-G-00001) Revision 5, Chapter 1, "Site Characteristics", Westinghouse Savannah River Company, Aiken, SC, September, 2000.

Other site-specific data and supplemental updated NPH information have been included per the additional listed references in this report.

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1.3 SITE DESCRIPTION

1.3.1 GEOGRAPHY

1.3.1.1 Location

The Plutonium Disposition Facilities are located within the F-Area of the Savannah River Site (SRS). F-Area is approximately centrally located within the SRS. SRS is an approximately circular tract of land occupying 310 square miles (198,344 acres) within Aiken, Barnwell, and Allendale Counties in southwestern South Carolina (Ref. 10). All of the area within a 5-mile (8-km) radius from the center of SRS is government-owned property. The center of SRS is approximately 25 miles (40 km) southeast of the city limits of Augusta, GA; 100 miles (160 km) from the Atlantic Coast; and about 110 miles (180 km) south-southeast of the North Carolina border. The SRS is bounded along 17 miles (27 km) of its southwest border by the Savannah River (see Figure 1.3-1). Regional safety considerations for the SRS are considered in the Site Generic Safety Analysis Report (G-GSAR-G-00001, Rev. 4).

Approximate distances to other locations of interest are given (in road miles) in Table 1.3-1. The site's location relative to towns, cities, and other political subdivisions within a 50-mile (80-km) radius is shown in Figure 1.3-2. The largest nearby population centers are Aiken, SC, and Augusta, GA (see Figure 1.3-2). The only towns within 15 miles (24 km) of the center of SRS are New Ellenton, Jackson, Barnwell, Snelling, and Williston, South Carolina, which are shown in Figure 1.3-3 (Ref. 11).

Prominent geographical features within 50 miles (80 km) of SRS are Thurmond Lake (formerly called Clarks Hill Reservoir) and the Savannah River. Thurmond Lake, operated by the U.S. Army Corps of Engineers, is the largest nearby public recreational area. This lake is an impoundment of the Savannah River about 40 miles (64 km) northwest of the center of SRS.

SRS consists of the following six major production areas:

- Reactor areas (C, K, L, P and R Areas)
- Separations areas (F and H Areas)
- Waste management areas (E, S, and Z Areas)
- Heavy water reprocessing area (D Area)
- Reactor materials area (M Area)
- Administration area (A Area)

Approximate latitude and longitude coordinates and SRS coordinates for the boundaries of SRS are given in Table 1.3-2. The SRS coordinates were developed during initial site construction. These coordinates are used in this report to define area and facility locations. The grid for SRS coordinates is referenced to the plant north direction, which has a declination of 36° 24'15" west of geographic north.

SEPARATIONS AREAS

F Area is located in Aiken County, South Carolina, near the center of SRS, east of Road C and north of Road E (see Figure 1.3-4). F Area center point coordinates are given in Table 1.3-2. The nearest site boundary to F Area is approximately 6 miles (9.5 km) to the west.

H Area is located in Aiken and Barnwell Counties, South Carolina, near the center of SRS (see Figure 1.3-4), to the east of F Area. H Area center point coordinates are given in Table 1.3-2. The nearest site boundary to H Area is approximately 7.2 miles (11.5 km) to the west.

WASTE MANAGEMENT AREAS

The E Area Solid Waste Management Facility (SWMF) is located in Aiken County, South Carolina, near the approximate center of SRS between H Area and F Area (see Figure 1.3-4). The SWMF center point coordinates are given in Table 1.3-2. The nearest site boundary to E Area is approximately 6.5 miles (10.5 km) to the west.

S Area is located in Aiken County, South Carolina, north of H Area (see Figure 1.3-4). The S Area center point coordinates are given in Table 1.3-2. The nearest site boundary to S Area is approximately 6.8 miles (10.9 km) to the north.

Z Area is located north of S and H Areas in Aiken County, South Carolina, near the center of SRS (see Figure 1.3-4). The Z Area center point coordinates are given in Table 1.3-2. The nearest site boundary to Z Area is approximately 6.2 miles (10 km) to the north.

1.3.1.2 Exclusion Area

GENERAL SITE

SRS is owned by the U.S. Government. It was set aside in 1950, as a controlled area, for the production of nuclear materials for national defense. The DOE and its contractors are responsible for the operation of SRS.

The site is not open to the general public, but specific access is permitted for guided tours, controlled deer hunts, and environmental studies. In addition, the public can traverse portions of the site along established transportation corridors. These include a rail line for CSX Transportation Incorporated Railroad, and road traffic along South Carolina Route (SCR) 125 (SRS Road A), U.S. Route 278, and SRS Road 1 near the northern edge of the site. Figure 1.3-3 shows these roadways and railways. Figure 1.3-4 shows the relative locations of the major areas at SRS and the SRS boundary. These areas are discussed in the following paragraphs.

The production areas at SRS are broadly classified as Reactor Materials (300-M Area), Heavy Water (400-D Area), Reactors (100 Areas), Separations (200-F and 200-H Areas), Waste Management Operations (200 Areas), and Defense Waste Processing (200-S and 200-Z Areas).

Other SRS areas include the Administrative (700-A and -B Areas) and General (600-G or -N) Areas. DOE and Westinghouse Administrative Offices, Production Support, SRTC, Production Services, and Savannah River Ecology Laboratory (SREL) are located in the 700-A Area. Wackenhut Services, Inc. (WSI), the contractor for SRS Security Services, is based in the 700-B Area; WSI personnel are located throughout SRS. All facilities scattered through SRS but outside of the fenced, production areas of SRS are designated with a 600 identification "building" number. The U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS), University of South Carolina Institute of Archaeology and Anthropology, USDA Savannah River Forest Station (SRFS), and river pumphouses are some of the facilities designated as 600-Area facilities.

The topographic relief of SRS and the surrounding vicinity is shown in Figure 1.3-5. Contour intervals shown are 50 feet. The elevation above sea level ranges from 80 feet at the Savannah River to approximately 400 feet about 1 mile south of the intersection of Highways 19 and 278. Two distinct physiographic subregions are represented at SRS. They are the Pleistocene Coastal Terraces, which are below 270 feet in elevation, and the Aiken Plateau, which is above 270 feet in elevation.

The lowest terrace is the present floodplain of the Savannah River. The higher terraces have level to gently rolling topography. The Aiken Plateau subregion is hilly and cut by small streams (Ref. 12).

Surface wind patterns and the occurrence of strong winds and tornadoes are discussed in Section 1.4.1.1. The wind rose developed from the 1987-1991 database is shown in Figure 1.3-6. As can be seen, there is no prevailing wind at SRS, which is typical for the lower midlands of South Carolina (Ref. 10).

Surface drainage on SRS is shown in Figure 1.3-7, and major river systems surrounding SRS are shown in Figure 1.3-8. Surface wind patterns and the occurrence of strong winds and tornadoes are discussed in Section 1.4.1.1.

The principal surface-water body associated with SRS is the Savannah River, which flows along the site's southwest border. Six principal tributaries to the Savannah River are located on SRS; these are Upper Three Runs Creek, Beaver Dam Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs Creek. The total drainage area of the Savannah River, 10,681 square miles, encompasses all or parts of 41 counties in Georgia, South Carolina, and North Carolina. More than 77% of this drainage area lies upriver from SRS.

Natural discharge patterns on the Savannah River are cyclical: the highest river levels are recorded in the winter and spring, and the lowest levels are recorded in the summer and fall. Stream flow on the Savannah River near the site is regulated by a series of three upstream reservoirs: Thurmond Lake, Russell, and Hartwell. These reservoirs have stabilized average annual stream flow to 10,200 cubic feet per second (cfs) near SRS.

The river overflows its channel and floods the swamps bordering the site when river elevation rises higher than 88.5 feet above msl (which corresponds to flows equal to or greater than 15,470 cfs). River-elevation measurements made at the SRS Boat Dock indicate that the swamp was flooded approximately 20% of the time (74 days per year on the average) during the period from 1958 through 1967.

The peak historic flood between the years 1954 and 1991 was estimated to be 84,500 cfs (Ref. 13). Since the construction of the upstream reservoirs, the maximum average monthly flow (during the period from 1964 to 1981) has been 43,867 cfs and occurs during the month of April (Ref. 14).

There are three significant breaches in the natural river levee at SRS; they are opposite the mouths of Beaver Dam Creek, Fourmile Branch, and Steel Creek. During periods of high river level (about 88.5 feet), river water overflows the levee and stream mouths and floods the entire swamp area. The water from these streams then mixes with river water and flows through the swamp parallel to the river and combines with the Pen Branch flow. Normally the flows of Steel Creek and Pen Branch converge 0.5 mile above the Steel Creek mouth. However, when the river level is high, the flows are diverted parallel to the river across the offsite Creek Plantation Swamp; ultimately, they join the Savannah River flow near Little Hell Landing (Ref. 15).

The topography at SRS varies from gently sloping to moderately steep. Some areas on uplands are nearly level, and those on bottom land along the major streams are level. The slopes in small, narrow areas adjacent to drainage ways are steep. Most of the soils are sandy over a loamy or clayey subsoil (Ref. 16). The well drained soils have a sandy surface layer underlain by a loamy subsoil. The somewhat excessively drained soils have a thick, sandy surface layer that extends to a depth of 80 inches or more in some areas. The soils on bottomland range from well drained to very poorly drained. In the Sand Hills area, some soils on the abrupt slope breaks have a dense, brittle subsoil. Numerous upland depressions, commonly referred to as "Carolina bays," are found on SRS. These range in size from less than an acre to many acres. Water will stand in the majority of these depressions for long periods, in most years.

The gradient of slopes at SRS ranges from 0 to 40%. The upland soils have a thick, well developed profile. The most extensive soils in the survey area are gently sloping to strongly sloping and have not been greatly affected by relief. The soils on bottomland have slopes of 0 to 2%. These soils are young and show little evidence of profile development.

Relief at SRS ranges from the long, narrow, steep areas on slopes on the east side of Upper Three Runs Creek and Tinker Creek to the nearly level areas on stream terraces west of Road 125. Elevations range from about 420 feet near the Aiken Gate House on Road 2 to about 70 feet where Lower Three Runs Creek enters the Savannah River in Allendale County. The elevation is about 80 feet where Steel Creek enters the Savannah River in Barnwell County. Most of the soils have slopes that range from about 1 to 8%. Some long, narrow breaks near streams have slopes that range to 40%.

Nearly all drainage from SRS is into the Savannah River. A small area in the northeast sector of SRS drains to the Salkehatchie River. The bottom land along the Savannah River is not flooded as extensively as it was prior to 1953 when Strom Thurmond Dam and other hydroelectric dams upstream began operation, which controlled runoff in the Savannah River. However, since streamflow is regulated somewhat by locks and the release of water through the dams, the frequency of flooding is greater, but the flooding is less severe.

Erosion is moderate on the gently sloping soils of SRS and severe on the sloping to steep soils. A permanent plant cover is needed on the more sloping soils. If land use prohibits a permanent plant cover, plant rotations, diversions or terraces, cover crops, crop residue management, and water-disposal systems should be used to control erosion (Ref. 16). Figure 1.3-9 shows the distribution of soil types as characterized by SCS. The engineering properties of SRS soils are described in Section 1.4.3.

In South Carolina, the average statewide erosion rate for soils is 6.3 tons per acre per year (T/AC/YR). The tolerable soil loss rate ranges from 2 to 5 T/AC/YR depending on the individual soil. Average soil erosion rates for the area surrounding SRS are 8.5 T/AC/YR for Aiken County, 6.8 T/AC/YR for Allendale County, and 9.0 T/AC/YR for Barnwell County (Ref. 17). The soils within SRS would be expected to have erosion rates somewhat lower than the surrounding area because SRS is covered, for the most part, with vegetation, and is not used for crop production.

The eight major plant community types at SRS are distributed along topographic and moisture gradients and are strongly controlled by local management practices. Communities range from sandhill communities in the xeric uplands to bottomland or swamp forests in low-lying areas subject to periodic flooding. The majority of the SRS land area is managed as pine plantation. However, old fields, upland hardwoods, and numerous aquatic communities including ponds, marshes, and Carolina bays cover approximately one-third of the land area on SRS (Ref. 18).

At the time of government acquisition, about 106,000 acres were forested, 68,000 acres were cleared fields, and 29,000 acres were floodplains and swamps. An intensive pine planting program and natural successional changes have dramatically altered these figures. Table 1.3-3 lists the vegetation cover of the site in 1989. Land utilization is about 56% in pine forests, 35% in hardwoods, 7% in SRS facilities and open fields, and 2% in water (Ref. 12).

The SRFS considers SRS to have an average to moderately high fire hazard potential. This fire hazard potential is caused by vast forested areas close to the production areas. Total and available fuel loading accumulations for a 5- to 10-year period are presented in Table 1.3-4. SRFS performs controlled burning to reduce the potential for forest fires. The primary impact of forest fires on the production areas is smoke, which causes visibility problems and potential damage to equipment. In fiscal year 1993, SRFS responded to 21 wildfires on and adjacent to the site. Six of these fires were in the mutual threat zone where the South Carolina Forestry Commission has primary protection responsibility. The remaining 15 fires burned 43 acres on the SRS.

The road system within SRS is shown in Figure 1.3-10. Continuation of these traffic routes offsite is shown in Figure 1.3-2. SRS highways connect with state highways leading northward to Interstate Routes 20, 26, and 85 and eastward to Interstate Routes 26 and 95. SRS has its own railroad system, which services all major facilities. Figure 1.3-11 shows the SRS rail system and the public railroad having rights-of-way onsite.

The rail network includes a main line of the CSX Railroad and the sitewide DOE-owned rail system. A classification yard is maintained near the 100-P Area, with plant-maintained connections to all of the production areas except the 400-D Area. Service to the 400-D Area is provided by the CSX tracks onto a short section of DOE-owned track. Rail traffic on the site is separated into two distinct categories according to ownership of the track: CSX operations and SRS operations. The CSX Railroad has a through line between Augusta, GA, and Yemassee, SC, and terminates in Port Royal, SC (Ref. 14). In 1989, a second line from SRS to Florence, SC was abandoned by CSX beyond Snelling, SC. CSX maintains service as required to the Dunbarton Station for SRS deliveries/pickups and a spur line into the Chem-Nuclear site near Snelling, SC.

The electrical grid on SRS operates at 115 kV and draws power from two transmission lines on separate rights-of-way from the South Carolina Electric and Gas (SCE&G) Urquhart Station and a third line from the 230-kV tie line between the Sumner and Canadys stations of SCE&G (see Figure 1.3-12). Their three feeders are tapped at SRS stations 504-1G, 504-2G, and 504-3G, respectively. The site 115-kV distribution system contains about 90 miles of power lines and is controlled by a dispatcher in Building 751-A (700-A Area) (Ref. 11). SRS also has a tie-in line to Vogtle Electric Generating Plant (VEGP). The tie-in line is shown in Figure 1.3-12. There are no natural gas or oil pipeline networks at SRS.

F AND E AREAS

F Area is centrally located within the SRS boundary (see Figure 1.3-4). Figure 1.3-13 shows F Area and the surrounding areas including the E Area. A detailed area map for F Area is shown in Figure 1.3-14.

F Area is drained by several tributaries of Upper Three Runs Creek approximately 2,200 feet to the north and west and by Fourmile Branch approximately 2,000 feet to the south. Topography in the vicinity is shown in Figure 1.3-15. Surface elevations across F Area range from approximately 200 to 320 feet msl.

F Area's main processing facility is F Canyon, which is composed of two chemical separations plants and associated waste storage facilities. In the past, the F Canyon was used to chemically separate uranium, plutonium, and fission products from irradiated fuel and target assemblies. The separated uranium and plutonium were transferred to other facilities for further processing and final use. The waste was transferred to high-level waste tanks in the area for storage. The F Area waste tank farm consists of 22 underground storage tanks that store high-level aqueous radioactive waste and evaporated saltcake.

Currently, F Canyon is conducting operations to stabilize SRS materials. Most of the stabilization actions will be the same as the historic mission (Ref. 10).

FB Line previously converted plutonium solution produced in F Canyon to plutonium-239 metal to support defense programs. FB Line's current mission is to convert plutonium-bearing solutions into a metal form suitable for storage (Ref. 10).

Analytical laboratories in F-Area (Buildings 772-F, 772-1F and 772-4F) principally support F- and H-Area reprocessing and waste activities.

The E Area Solid Waste Management Facility (SWMF) occupies 195 acres between the F and H Areas. The SWMF is used for permanent disposal of low-level radioactive solid waste and interim storage of radioactive, hazardous and mixed solid waste generated at SRS, as well as occasional special shipments from offsite. The SWMF also provides assaying, repackaging, and interim storage of transuranic (TRU) waste (Ref. 19). Other SRS facilities receive hazardous, low-level, and mixed waste for incineration and nonradioactive and hazardous waste for storage (Ref. 19). An area map is shown in Figure 1.3-16. Topography near F and E Areas is shown in Figure 1.3-15.

H, S, AND Z AREAS

H Area is located east of the SWMF near the center of SRS (see Figures 1.3-4 and 1.3-13). A detailed area map of H Area is shown in Figure 1.3-17.

Topography near H Area is shown in Figure 1.3-18. A topographic high runs through the E Area SWMF and into H Area. H Area is located near a water-table divide between Upper Three Runs Creek and Fourmile Branch. Near-surface groundwater from the southern part of H Area discharges to an unnamed tributary of Fourmile Branch, approximately 1,000 feet south of H Area. Near-surface groundwater from the northern part of H Area discharges to one of two tributaries (Crouch Branch or McQueen Branch) of Upper Three Runs Creek, which are approximately 1,500 and 4,000 feet north of H Area, respectively.

H Area covers approximately 395 acres; surface areas across H Area range from approximately 270 to 315 feet msl. In the past, H Canyon, a large, shielded chemical separations plant, processed irradiated fuel and target assemblies by utilizing solvent extraction and ion exchange to separate uranium, plutonium, and fission products from waste. The separated uranium and plutonium were transferred to other H Area facilities for processing into a solid form. The waste was transferred to high-level waste tanks in the area for storage, and some of the nuclear materials were shipped to other DOE sites for final use. DOE has issued a decision that H Canyon should be used to convert highly enriched weapons grade uranium to a low enriched form not useable for weapons production (Ref. 20).

HB Line was constructed to support the production of plutonium-238. Plutonium-238 has a unique combination of heat output and long life allowing space vehicle designers to keep weight at a minimum and still have a power supply. For example, in the mid-1990s, the HB Line completed a production run to supply plutonium-238 for the Cassini mission, an unmanned expedition to the planet Saturn. HB Line is also used to stabilize plutonium-242 solutions (Ref. 20).

The tritium facilities in H Area consist of four main process buildings, designed for and operated to process tritium. The newest building is the 1-acre underground Replacement Tritium Facility (RTF). The main mission of the tritium facilities is to purify and maintain existing inventories of tritium for defense purposes (Ref. 20).

The Receiving Basin for Offsite Fuels (RBOF) is also located in H Area. Offsite fuels that will be processed in H Canyon are stored and packaged at RBOF. Radioactive waste generated by RBOF is stored in the high-level waste tanks in H Area (Ref. 20).

The Effluent Treatment Facility (ETF) is located on the south side of H Area. The ETF treats low-level radioactive wastewater (which was formerly sent to seepage basins). The ETF removes radioactive and nonradioactive contaminants, except tritium, from process effluents and allows the water to discharge to Upper three Runs Creek (Ref. 20).

The H Area waste tank farm consists of 29 large (up to 1.3 million gallon capacity) underground storage tanks that store high-level aqueous radioactive waste and evaporated saltcake. Seven of these tanks are now dedicated as In-Tank Precipitation Facility (ITPF) process tanks (Ref. 20).

The Consolidated Incineration Facility (CIF) is located on the east side of H Area. The CIF incinerates SRS hazardous, mixed, and low-level radioactive waste (Ref. 20).

S Area is located north of H Area near the center of SRS (see Figures 1.3-4 and 1.3-13). A detailed area map of S Area is shown in Figure 1.3-19.

Surface elevations across S Area range from approximately 300 to 320 feet msl. Surface drainage is to the east toward McQueen Branch and to the west toward Crouch Branch, both tributaries of Upper Three Runs Creek. Near-surface groundwater flows toward McQueen Branch, approximately 4,000 feet to the northeast. Topography near S Area is shown in Figure 1.3-20. The elevation above sea level is about 300 feet at the site, 150 feet at Upper Three Runs Creek 0.8 miles northwest of the S-Area fence, and 200 to 250 feet at Fourmile Branch to the south. The Savannah River, into which these streams feed some 9 miles to the southwest, is usually at an elevation of about 8 feet msl, or slightly greater. Flooding of site streams begins at a river height of 88.5 feet msl.

S Area is the site of the Defense Waste Processing Facility (DWPF) Vitrification Plant. The DWPF immobilizes high level radioactive waste sludge and precipitate by "vitrifying" it into a solid glass waste form (Ref. 20).

Z Area, which contains the DWPF Saltstone Facility, is located north of the intersection of Road F and Road 4. A detailed map of Z Area is shown in Figure 1.3-21. The Saltstone Facility treats and disposes of the filtrate created by the ITPF by stabilizing it in a solid, cement-based waste form (Ref. 20).

The original topography near Z Area is shown in Figure 1.3-22. Before grading for installation of facilities, Z-Area ground surface elevations ranged from approximately 280 to 300 feet msl. This site was selected for saltstone disposal because it is located on a well-drained topographic high, as evidenced by the lack of marshes or other bodies of standing water. Natural drainage from Z Area enters McQueen Branch, Crouch Branch, and Upper Three Runs Creek. These flow to the Savannah River. During construction of the Z-Area facilities, anthropogenic alterations to surface water drainage patterns were made. All surface water runoff, from around the saltstone disposal vaults and the Saltstone Production Facility, has been directed through a stormwater collection system and into a retention basin for silt removal. The retention basin overflows into a channel that drains to McQueen Branch.

SITE BOUNDARY

Activities conducted within SRS that are not under the control of the operating contractor, WSRC, and not related to production, are performed by the following organizations: General Services Administration (GSA), WSI, SRFS, SREL, University of South Carolina Institute of Archaeology and Anthropology, SCS, and SCE&G.

General Services Administration

The GSA is a federal agency that operates at SRS under a Memorandum of Agreement with DOE. The GSA SRS Field Office, located at SRS, is part of the South Carolina Fleet Management Center. GSA maintains the federal vehicle fleet from "cradle to grave," including acquisition, maintenance, and disposal. Eleven GSA employees are stationed in A Area.

Wackenhut Services, Inc.

WSI provides security services for SRS. These include preventing unauthorized access to site facilities, equipment, information, and personnel; restricting the impact of any unauthorized access on the site; badging; manning the various site access portals; and providing appropriate training for all security personnel.

WSI is headquartered in 700-B Area and performs security activities in all major areas. WSI facilities and personnel are distributed throughout the site. In addition, WSI uses the Small Arms Training Area and the Advanced Tactical Training Area (Ref. 11, 22).

Savannah River Forest Station

SRFS, an administrative unit of the U.S. Forest Service (USFS) provides timber management, plant and wildlife management, secondary road maintenance, and maintenance of the exterior boundaries at the SRS. SRFS manages approximately 175,000 acres or about 80% of the site area. SRFS fire crews, which have primary responsibility for fighting wild fires and conducting controlled burns, coordinate their efforts with the WSRC Fire Department (Ref. 20).

SRFS occupies or uses six buildings along SRS Road 2 about 2.5 miles south of US 278 and approximately 7 acres of adjoining land. The buildings are used for office space and equipment and material storage (Ref. 22).

Savannah River Ecology Laboratory

SREL is operated for DOE-Savannah River by the University of Georgia. The mission of SREL is to study and assess the impact of site operations on the environment. Research programs are organized into four main categories: radioecology, environmental chemistry, ecotoxicology, and ecosystem health (Ref. 20).

SREL occupies or uses approximately 30 acres of land. Land uses include offices, laboratories, shops, greenhouses, ponds, and research facilities. Most of SREL's buildings are located in A Area, southeast of SRTC.

University of South Carolina Institute of Archaeology and Anthropology

The mission of the University of South Carolina Institute of Archaeology and Anthropology is to make compliance recommendations to DOE that will facilitate the management of archaeological resources at SRS. This includes compliance activities involving reconnaissance surveys, general intensive watershed surveys, specific intensive surveys, data recovery, coordination with major land users, and reconstruction of the environmental history of the SRS (Ref. 20).

The Institute occupies offices in Building 760-11G, and uses adjacent grounds in the SRFS area (Ref. 22).

Soil Conservation Service, U.S. Department of Agriculture

The mission of SCS is to publish a soils report of SRS that meets the standards of the National Cooperative Soil Survey. Current land use includes one office in Building 760-11G and the surrounding grounds (Ref. 22).South Carolina Electric and Gas Company

SCE&G leased the D-Area powerhouse in 1995. This facility is the site's largest coal-fired powerhouse; it provides approximately 70 megawatts of electric capacity and 420,000 lb/hr of process steam capacity (Ref. 20).

BOUNDARIES FOR ESTABLISHING EFFLUENT RELEASE LIMITS

The outer perimeter fenceline of SRS is used as the basis for specification limits on the release of gaseous and liquid effluents from all SRS facilities. The outer perimeter of SRS is shown in Figure 1.3-27 (Note: Figures 1.3-23 through 1.3-26 are intentionally omitted). The Figure also shows Emergency Planning Zone/Contingency Planning Zone (EPZ/CPZ) boundaries with respect to rivers and streams. The outer perimeter is fenced, and access is controlled by the security contractor (WSI) with the assistance of the operating contractor such that public access can be restricted as the need arises. The roads that pass through or near the perimeter can be blocked by WSI personnel or with the assistance of local, law enforcement personnel.

The EPZ shown in Figure 1.3-27 is based on the Design Basis Accident under worst meteorological conditions at the reactors. Only a small portion of the EPZ extends outside the SRS boundary. The CPZ, an arbitrary zone that is within an approximately 10-mile (16-km) radius from each reactor, was established when the reactors were operating. The location of the SRS boundary with respect to rivers and population centers is shown in Figure 1.3-2.

The closest potential release points are M Area, which is approximately 1 mile (1.6 km) from the outer perimeter boundary, and SRTC, which is about 0.5 mile (0.8 km) from the outer perimeter boundary. The 200 Areas, where Separations and Waste Management facilities are located, have the largest inventory of radioactive materials that could potentially be released, and are located greater than 5 miles (8 km) from the site boundary (see Figure 1.3-4).

Onsite personnel are provided with dosimeters if they are entering potential radiation areas. Production areas enforce more stringent access controls, including special dosimeters and protective clothing, additional access authorization, and escorts for visitors. Dose equivalents to the general public and site personnel are kept As Low As Reasonably Achievable (ALARA). The limits for radiation exposure from external and internal exposure are stated in 10 Code of Federal Regulations (CFR) 835, Occupational Radiation Protection (Ref. 23). The 10 CFR 835 limit to radiation workers is 5 roentgens equivalent man (rem) total Effective Dose Equivalent (EDE). However, the DOE Administrative Control Level for a radiation worker is 2 rem/year total EDE. 10 CFR 835 further limits exposure of nonworkers, during onsite access at a DOE facility, to no more than 0.1 rem (100 mrem) per year. DOE Order 5400.5, Radiation Protection of the Public and the Environment, limits the exposure of members of the public to all radioactive sources from DOE activities to no more than 100 mrem EDE per year (Ref. 24).

ACCESS CONTROL

The outer perimeter of SRS is fenced; access is controlled by the operating contractor with the assistance of the security contractor, WSI. General access to the plant site, with the exception of public transportation corridors, is limited to badged personnel.

SCR 125 is a public access corridor and is not controlled. The CSX rail line maintains a right-of-way through the site, without barricades at either end of the site. Although these entries do not restrict pedestrian access, access would be into a nonsecured area of SRS with further entry into secured areas restricted by barricades.

Visitors to SRS must wear identification badges, and those entering areas where there is a radiation hazard are required to wear dosimeters. The roads that pass through or near the perimeter can be blocked by WSI personnel or with the assistance of local, law enforcement personnel.

Employee access within the F and H Area fences is controlled by security personnel, and restricted to employees who have the appropriate designation on their security badges. More restrictive individual facilities within F and H Areas have additional access requirements. Access to E Area is controlled by a perimeter fence and procedural controls; no security personnel are posted at the entry gate adjacent to Building 742-7E.

S and Z Areas are property protection areas. M Area is also a property protection area. Individual facilities within M Area have additional access requirements. Access to SRTC is limited to personnel with "L" clearance or higher, unless escorted. D Area is a property protection area.

EFFLUENT RELEASE POINTS

The WSRC Environmental Protection Department maintains an active permit inventory for National Pollutant Discharge Elimination System (NPDES) permitted outfalls and permitted air emission sources. The annual Environmental Data Report contains a listing of NPDES outfall locations and the sources of wastewater contained in each effluent. The Annual Environmental Report for SRS contains an annually updated listing of all air permits held by SRS, including permit number, permit title, and permitted source (Ref. 20).

RELEVANT SPECIAL FEATURES

SRS is a self-contained site that provides its own security, fire protection, medical, maintenance, and other services. To enhance the safety of the facility, a large support staff provides services such as radiological protection, industrial hygiene, and safety. In addition to the onsite resources, which include specialized equipment for tracking tritium releases, meteorological assessment systems, and monitoring equipment, a large supply of specialized equipment is available from regional DOE offices. State agencies in South Carolina and Georgia, VEGP, Fort Gordon, and other nearby sources can also provide monitoring equipment, medical facilities, and laboratory facilities in emergencies. In addition, several municipal emergency organizations are located within 25 miles of SRS. These resources are discussed in Chapter 15.0 of this report.

1.3.2 DEMOGRAPHY

1.3.2.1 Permanent Population and Distribution

GENERAL SITE

The total resident population within a 50-mile (80-km) radius of the SRS center is approximately 730,000. The largest urban center, Augusta, GA (1990 population of 44,639), lies about 25 miles (40 km) west-northwest of the site. Four other cities within the 50-mile radius had 1990 populations greater than 13,000. These are Aiken, SC, about 20 miles (32 km) north-northwest; Orangeburg, SC, 48 miles (77 km) east-northeast; North Augusta, SC, 23 miles (37 km) northwest; and Evans, GA, about 35 miles (56 km) west-northwest of the site. All other cities and towns have populations less than 7,000; the largest is Belvedere, SC, followed by Red Bank, SC; Waynesboro, GA; and Barnwell, SC (Ref. 25). Table 1.3-5 shows the sizes and geographic locations of cities and towns within the 50-mile radius.

The SRS Emergency Plan Section 3 and facility annexes establish the interrelationships with federal, state, and local organizations for offsite emergency response and for the protection of the environment and the public. Population evacuation estimates are given in the SRS Emergency Plan SCD-7 (Ref. 26). Details on emergency preparedness and the SRS Emergency Plan can be found in Chapter 15 of this report.

Projected permanent populations (residents) and their distribution within a 50-mile (80-km) radius of the plant center were updated by the Environmental Technology Section (ETS) at SRTC (Ref. 27). The "Potential Security Circle for the Savannah River Site" was used to establish the center of SRS at plant coordinates E58,000; N62,000. The 1990 census at 0.025-degree grids of latitude and longitude was used as the database. This database was used by ETS to derive population densities at 15-second cells of latitude and longitude. The results were aggregated by the geographical divisions formed by subdividing the study area into 16 radial segments centered on north and concentric circles with radii of 5, 10, 20, 30, 40, and 50 miles. The area within a radius up to 5 miles from the SRS centroid is contained within the SRS boundary. Therefore, zero permanent population exists within radii up to 5 miles. An offsite population database, based on the results of the 1990 census, was used to update populations (Ref. 27). Projections were based on the assumption that the growth rate will be similar to the growth rate of the total population in the WNW sector around 200-S Area (Ref. 27).

The growth, by decennial years, is determined using the following ratios:

Year	Population Ratio of Given Year to 1990
1990	1.000
2000	1.140
2010	1.299
2020	1.481
2030	1.688
2040	1.924

Figures 1.3-28 through 1.3-33 show the 1990 population distribution and the projected population distributions for radii 10 through 50 miles (16 through 80 km) from site center for 1990, 2000, 2010, 2020, 2030, and 2040 (Ref. 28).

Both South Carolina and Georgia have projected population compositions by county and age group for 1990 (Ref. 22, 25). The 1990 age group composition projections for the counties within 50 miles (80 km) of SRS include the following:

	Age Group (%)			
	0-4 years	5-18 years	18-64 years	65 years and over
Georgia	8.14	27.13	54.62	10.11
South Carolina	7.60	19.91	61.25	11.24

F AND E AREA

The permanent population consists of residents within a 50-mile (80-km) radius of F Area. Projected permanent populations and their distribution within a 50-mile radius of F Area were estimated for 10-year intervals through 2040, based on 1990 census data, by the SRTC (Ref. 28). The results were aggregated by geographical divisions formed by subdividing the study area into 16 radial segments. The segments are centered on north and concentric circles with radii of 1, 2, 3, 4, 5, 10, 20, 30, 40, and 50 miles (see Figures 1.3-34 through 1.3-39). These are based on the "Potential Security Circle for the Savannah River Site," which was modified to establish the F Area center point at SRS coordinates E51,345; N77,687. The areas within the 1- through 5-mile radii are DOE-owned properties within SRS; the population for these areas consists of SRS workers only.

Since the SWMF is within a few thousand feet of F Area, the population distributions for F Area shown in Figures 1.3-34 through 1.3-39 are adequate for SWMF assessments.H, S, and Z Areas

Since the H, S, and Z Areas are all within 1.5 to 2 miles of F Area, the population distributions for F Area shown in Figures 1.3-34 through 1.3-39 are adequate for assessment of H, S, and Z Areas. H, S, and Z Areas are farther away from the largest population centers in Richmond and Columbia Counties, Georgia, and Aiken County, South Carolina.

1.3.2.2 Transient Population Variations

Transient population variations for SRS are addressed for the areas within approximately 5 miles (8 km) of the various SRS activities. Any transient population fluctuations beyond this limit are not relevant to a SAR. The transient population components investigated are industrial, school, recreational, health care, and casual. There are no military reservations or correctional institutions located within 5 miles of the site boundary.

The transient population consists of all persons traveling through the vicinity of an onsite area. A 5-mile (8-km) radius is considered when discussing the transient population. The 5-mile areas for F and E Areas, and H, S, and Z Areas, shown in Figures 1.3-52 and 1.3-53, respectively, fall entirely within the SRS boundary (Note: Figures 1.3-40 through 1.3-51 are intentionally omitted). Therefore, the transient population consists only of employees, badged visitors, and vendors making deliveries at site locations within the area.

INDUSTRIAL POPULATION

The industrial population, consisting primarily of the SRS workforce, VEGP employees, and employees of 16 smaller industries located in or near Barnwell, Williston, New Ellenton, and Jackson, South Carolina, comprise a daily transient population of approximately 25,734. Most of this total population works Monday through Friday during the hours 0800 to 1600. These workers spend an average of about 45 hours per worker, per week, at their worksites.

The total onsite employment at SRS during the day shift of a weekday was 14,177 as of December 1998. According to unofficial information provided by the WSRC Public Affairs Department (Bruce Cadotte, February 1999), the distribution of onsite employees working the day shift on a weekday was estimated to be WSRC 12,622; DOE 520; WSI 742; and the rest in the USFS, SREL, and other contractors to DOE-SR.

Figure 1.3-56 boundary (Note: Figures 1.3-54 and 1.3-55 are intentionally omitted). shows total onsite population densities at SRS based on 1993 data (Ref. 29). SRS population densities were developed specifically for environmental consequence assessments, using the population of adult workers at their assigned locations during the day shift of a weekday in midsummer 1993 (Ref. 29). For multishift operating areas, it was estimated that 70% of their workforce would be present during the daytime. All construction workers were assumed to be at their paymaster locations. A total onsite population of 19,289 was obtained from November 1992 data, and population densities by 15-second cells of latitude and longitude were determined for the database.

Geographical divisions were formed by subdividing the study area into 16 radial segments centered on north and concentric circles with radii of 1, 2, 3, 4, and 5 miles. Onsite population projections were not extrapolated from the above data due to uncertainties in predicting growth characteristics at SRS.

VEGP, located on the Savannah River in Burke County, Georgia, employs approximately 890 personnel (Ref. 30).

The industrial population within a 5-mile (8-km) radius of F and E Areas consists entirely of SRS employees at A/M, B, C, N, E, F, H, K, S, and Z Areas. The current workforce population, by area, is presented in Table 1.3-6 (Ref. 31).

The industrial population within a 5-mile (8-km) radius of H, S, and Z Areas consists entirely of SRS employees at B, C, N, E, F, H, R, S, and Z Areas. The current workforce population, by area, is presented in Table 1.3-7 (Ref. 32).

The industrial population on SRS within 5 miles (8 km) of M and A Areas (including SRTC) includes the SREL, 700-A Area, 700-B Area, M Area, and SRFS. Table 1.3-8 displays the population for the A and M Areas (including G Area, SREL, SRFS), and B Area. There are several small businesses, such as a well drilling service and a welding shop, located in Jackson and New Ellenton, South Carolina.

The industrial population on SRS within 5 miles (8 km) of D Area includes 186 employees at TNX Area, which includes the SCE&G personnel operating the powerhouse; 100 K Area (1,111 employees); and 100-C Area (831 employees). The only industry within 5 miles of D Area outside of SRS is VEGP, with a population of 890 (Ref. 30).

SCHOOL POPULATION

The existing public school population within 5 miles (8 km) of the site boundary consists of students and school personnel associated with 11 public schools located in New Ellenton, Jackson, Williston, and Barnwell, South Carolina (Ref. 25). No Georgia schools are located within 5 miles of the plant boundary (a school in Girard, GA was closed in 1987). The public school enrollment and distribution within 5 miles (8 km) of the SRS boundary are shown in Table 1.3-9 (Ref. 33). The locations of public schools in relation to the site are shown in Figure 1.3-57.

Public schools operate approximately 180 days per year, normally Monday through Friday, from late August through late May. There are no private schools or colleges in the 5-mile (8-km) vicinity.

RECREATIONAL POPULATION

The primary recreational activity within a 5-mile (8-km) radius of SRS production areas is controlled sport hunting. Hunts at SRS, supervised by DOE, are conducted annually with the benefit of controlling deer and feral hog populations. The SRS Annual Environmental Report includes numbers of hunts and numbers of animals killed (Ref. 20).

Hunting also takes place at Crackerneck, an area of 4,780 acres, west of SRS in Aiken County. The South Carolina Department of Natural Resources (SCDNR) manages Hunts at Crackerneck for deer, hogs, small game, and waterfowl, although permits are issued by DOE (Ref. 34). Another sporting area within 5 miles of SRS is a private commercial area of 4,000 acres about 15 miles (24 km) east of Waynesboro, GA. Hunting and/or fishing, as well as available lodging, are available to the public all year for a fee. No records of usage are available.

Additional recreational usage near the vicinity is available at three state parks located outside of the 5-mile (8-km) radius of SRS production areas, but within 12 miles (19 km) of the site boundary. These areas include Redcliffe State Park a historic site located off SCR 278 at Beech Island; Aiken State Park located off U.S. Route 78, 16 miles (25 km) east of Aiken; and Barnwell State Park off SCR 3 near Blackville. Table 1.3-10 shows the yearly usage at each of the state parks (Ref. 35). During fiscal year 1994/1995, total park usage was approximately 116,000 visitor days. All of the parks are available to the public year-round.

Other recreational activities within the 5-mile (8-km) radius of SRS production areas include fishing and boating. Numerous boat landings are located on the west bank of the Savannah River, which borders the southwestern portion of the site. In addition, a 95-acre man-made lake, Lake Edgar Brown, is located within the city limits of Barnwell. No records of usage at these areas are available. Boat landings and boat registration in several surrounding counties are discussed in Section 1.3.3.2.

HEALTH CARE POPULATIONS

One hospital and three nursing homes are located within 5 miles (8 km) of the SRS boundary. Table 1.3-11 shows the facilities by type, location, and the number of licensed beds at each facility. Total licensed bed space was 163 in 1997 (Ref. 36). In addition to the above mentioned facilities, there are two facilities that provide community residential care with a population of 15 residents and four facilities that provide intermediate care for the mentally retarded with a population of 32 residents in 1997 (Ref. 36).

CASUAL TRANSIENTS

Casual transients are people who travel through the site on private business. Primarily, the casual transient population consists of vehicle passengers traveling U.S. Route 278, SCR 125, SCR 19 via SRS Road 1; freight train personnel of the CSX Railroad; and aircraft occupants using the Barnwell County Airport.

WSI no longer issues travel passes for SCR 125, located on SRS. However, unofficial data previously collected from travel passes at gate locations through June 1988 show that during a 6-day period, 953 vehicles traveled north on Route 125, and an average of 1,607 traveled south. A small unknown percentage of these estimates represents plant traffic to the 400-D Area. Major entries onto SCR 125 from the north are U.S. Route 78 via U.S. Route 278 from North Augusta and SCRs 302 and 19 via SRS Road 1 from Aiken. Entries from the south include U.S. Route 278 from Allendale and SCR 3 from Barnwell. Traffic count maps obtained from the South Carolina Department of Transportation indicate that approximately 4,600 vehicles per day travel on U.S. Route 278 between SCR 302 in Aiken County to SCR 37 in Barnwell County. Major entries onto U.S. Route 278 are SCRs 302, 19, and 781 from U.S. Route 78 (Ref. 37).

The plant road system consists of over 120 miles (190 km) of primary roads (Ref. 38). The SRS Transportation Department is responsible for the majority of the operations traffic, which includes centralized trucking and waste hauling. Road traffic frequency is available in the Traffic Services Report (Ref. 39).

Construction traffic, both cars and trucks, results from the activities of BSRI and WSRC; construction transportation, other than construction personnel, includes equipment and materials. Construction traffic is routed either directly to a construction site or through the Central Stores area and then to a construction site. BSRI provides mobile equipment for all construction contractors onsite. Estimates of construction equipment usage and trucking operations can be found in the Traffic Services Report (Ref. 39). The heaviest road usage is on Roads 4, C, and 5.

Vendor trucking to and from SRS adds to the additional casual transient population. According to unofficial information provided by the WSRC Transportation Department (Hal Brinke, February 3, 1994), approximately 30 trucks per day off-load at Central Stores in Building 731-1N for distribution to various plant areas, and about 15 trucks per day go directly to other areas for delivery.

Traffic is counted periodically on plant roads by WSI. Selected 1996/1997 traffic count information for some of the most heavily traveled road segments is presented in Table 1.3-12. The traffic counts are based on a 24-hour period.

Personnel transport involves both private and government-owned passenger vehicles and trucks. Private vehicle traffic peaks at the commuter rush hours. During the day, most private vehicles remain parked, with government-owned and other official vehicles comprising the major portion of the traffic. Traffic counts at the various site gates are given in the Site Development and Facility Utilization Plan (Ref. 11, 22, 40).

The rail transient population on SRS consists of the crews of the CSX Railroad. A section of the Augusta, GA to Yemassee, SC line operates through SRS. This lines continues to Dunbarton Station, and on to Chem Nuclear Systems, Inc. (CNSI) near Snelling, SC, from the junction with the main line on SRS. The main line from Augusta, GA, east to Yemassee, SC, continues to operate (see Figure 1.3-11). In 1998, SRS had four shipments (approximately one shipment per quarter) into the site boundary. Each shipment consisted of approximately 10 rail cars.

In 1998, the number of inbound rail cars was 40. After all reactors were shut down, the volume of rail traffic decreased.

A Norfolk-Southern railroad track passes within 5 miles (8 km) of the SRS boundary; this track runs from Augusta, GA, to Charleston, SC, passing through Aiken (west of the site) and Williston (east of the site) (Ref. 41).

F AND E AREAS

The casual transient population consists of persons who travel through the vicinity of F Area and E Area. SCR 125 passes through the 5-mile (8-km) radius of F Area and E Area. Data from WSI officials, based on travel passes issued at the plant gate on SCR 125, indicate that 953 vehicles traveled north and 1,607 vehicles traveled south during a 6-day period in 1988. No public railroads pass within 5 miles of F Area and E Area; only the SRS rail operations falls within the 5-mile radius surrounding the H, S, and Z Areas. The remainder of the casual transient population consists primarily of personnel traveling between site areas on roads (Ref. 11).

H, S, AND Z AREAS

The casual transient population consists of persons who travel through the vicinity of H, S, and Z Areas. SCR 125 passes through the 5-mile (8-km) radius of these areas. Data from WSI officials, based on travel passes issued at the site gate on SCR 125, indicate that 953 vehicles traveled north and 1,607 vehicles traveled south during a 6-day period in 1988. No public railroads pass within 5 miles of H, S, and Z Areas; only the SRS rail operations fall within the 5-mile radius surrounding the H, S, and Z Areas. The remainder of the casual transient population consists primarily of personnel traveling between site areas on roads (Ref. 11).

1.3.3 USES OF NEARBY LAND AND WATERS

Land use within approximately 5 miles (8 km) of the SRS boundary is discussed in this section. The total area investigated is approximately 800 square miles (2,070 km^2). Of these 800 square miles, 310 square miles (800 km^2) are used for industrial purposes associated with the operation of SRS and for commercial and noncommercial timber management. DOE manages the land that forms a buffer zone around the production facilities. The countryside surrounding SRS is predominantly forested.

Land within a 5-mile (8-km) radius of F and E Areas, and H, S and Z Areas lies completely within SRS and is used for industrial purposes associated with SRS (see Table 1.3-13) and as forestland. Forested areas are managed by the SRFS, an administrative unit of the USFS. Through an interagency agreement between DOE and the USDA, the USFS maintains the SRFS to provide timber management, research support, soil and water protection, wildlife management, secondary road management, and fire management. The land in the affected area is primarily used for timbering. Small tracts of land are clear-cut on a rotating basis.

Approximately 55% of the land within a 5-mile (8-km) radius of A and M Areas is within the SRS boundary, with the remaining 45% of the land outside of the SRS boundary in Aiken County, South Carolina. Approximately 65% of the land, within a 5-mile radius of D Area, is within the SRS boundary, with the remaining 35% of the land outside of the SRS boundary in Burke County, Georgia. Land within the 5-mile radius of SRS is used for industrial purposes associated with SRS (see Table 1.3-13) and as forestland. Forested areas are managed by SRFS, an administrative unit of USFS.

The countryside surrounding SRS is predominantly forested; some land is farmed. Farming in this area is diversified. The main crops are soybeans, corn, wheat, cotton, peaches, peanuts, and various vegetable crops (Ref. 42-44).

1.3.3.1 Land Use

Land use at SRS is listed in Table 1.3-13.

SAVANNAH RIVER SITE OPERATIONS ACTIVITIES

SRS consists of seven major operating areas: reactor areas (C, K, L, P and R Areas); separations areas (F and H Areas); waste management areas (E, G, S, and Z Areas); heavy water reprocessing area (D Area); reactor materials area (M Area); and administration area (A Area).

The five nuclear production reactor facilities (C, L, P, K, and R) occupy 934 acres of SRS. All five reactors have been placed in cold shutdown. The approximate locations of the reactors areas are shown in Figure 1.3-4. Although the reactor areas are being used for moderator and fuel storage, no effort is being expended to maintain production capability of these reactors (Ref. 20).

The two separations areas, F and H (see Figure 1.3-4), occupy 364 and 395 acres, respectively. F and H Area operations are now primarily the stabilization of radioactive waste, maintaining tritium stockpiles, and reprocessing highly enriched weapons grade material to lower enrichment levels (Ref. 20).

The E Area Solid Waste Management Facility (SWMF) occupies 195 acres between the F and H Separations Areas. The SWMF is used for disposal and/or storage of radioactive, hazardous, and mixed solid waste generated at SRS, as well as occasional special shipments from offsite. It also provides interim storage for transuranic waste (Ref. 19, 20). Other facilities receive hazardous, low-level, and mixed waste for incineration and nonradioactive and hazardous waste for storage (Ref. 19). An area map is shown in Figure 1.3-16. Topography near F and E Areas is shown in Figure 1.3-4.

The 400-D Area (see Figure 1.3-4) occupies 445 acres at SRS. The D-Area Heavy Water Rework Facility is still in operation. Degraded heavy water is sent to the facility where light water is removed and the heavy water is reconcentrated to 99.75% purity (Ref. 20).

A coal-fired power plant is also located in D Area. The power plant is leased and operated by SCE&G (Ref. 20).

The 300-M Area (see Figure 1.3-4) occupies approximately 114 acres. M Area previously provided support to the reactor facilities, heavy water facilities, and the fuel fabrication facilities. The operations of these laboratories have been discontinued. M Area is comprised of Buildings 313-M (including the Chemical Transfer Facility [CTF]), 316-M, 320-M, 321-M, 322-M, 330-M, 331-M, 340-M, and 341-M. Most of the buildings in M Area are used to store radioactive material and waste (Ref. 21).

The Liquid Effluent Treatment Facility (LETF) is operating and consists of the Dilute Effluent Treatment Facility (DETF) in 341-M and the CTF. The IT/SF 341-1M remains in operation. The waste that is stored in the IT/SF tanks is being processed as feed material for the VTP (Ref. 21).

Vendor Treatment Process

The 700 Area (see Figure 1.3-4) consists of WSRC and DOE administrative groups, production support, SRTC, production services, and SREL. The 700 Area occupies 348 acres. A detailed area map of A Area (and the adjacent M Area) is shown in Figure 1.3-23. A Area is divided into two major fenced areas referred to as the Upper 700 Area and the Lower 700 Area (Ref. 20).

General site administrative functions are centered in A Area. The main DOE and WSRC headquarters are housed in the upper 700 Area in Building 703-A. Other organizations in A Area provide scientific and logistical support for SRS operations. SRTC supports the missions of SRS through applied research and development. SRTC is housed in buildings in the Technical Area, located in the upper 700 Area (Ref. 20).

OTHER SAVANNAH RIVER SITE ACTIVITIES

SREL, located adjacent to A Area, is operated by the University of Georgia. SREL conducts ecological studies on SRS, which was designated a National Environmental Research Park (NERP) in 1972. In addition, 891 acres are set aside in ten separate reserve areas for special studies (Ref. 11).

USFS Headquarters for the SRS land management program is located at the former U.S. Army anti-aircraft headquarters site, approximately 1.25 miles (2 km) south of the SRS barricade on SCR 19 (SRS Road 2). In addition to managing SRS timber, the USFS manages 60 acres of land set aside in two natural areas registered with the Society of American Foresters.

In June 1972, SRS was designated as the nation's first NERP. The areas of the site outside of the various production areas qualify as protected natural areas ideally suited for many kinds of ecological research. The basic concept of NERP is to provide an area, under a significant degree of protection from uncontrolled human influences, where environmental and ecological research can be conducted by qualified institutions and individuals (Ref. 20).

ACTIVITIES OUTSIDE THE SAVANNAH RIVER SITE BOUNDARY

Land in the surrounding countryside is used predominantly for forest and agriculture. The main agriculture products are soybeans, corn, wheat, cotton, peaches, peanuts, and various vegetable crops (Ref. 42-44). Tables 1.3-14, 1.3-15, and 1.3-16 list the numbers and sizes of farms in Aiken, Allendale, and Barnwell Counties, South Carolina, for 1981 through 1992 (Ref. 42-44). Agricultural and forestland uses for Richmond and Burke Counties, Georgia, are listed in Table 1.3-17.

Industrial land uses surrounding SRS are discussed in detail in Section 1.7.2.

LOCALIZED POPULATIONS

Localized populations for existing nearby industries and schools are described in Section 1.3.2.2.

1.3.3.2 Water Use

The major rivers near SRS include the Savannah, Salkehatchie, and South Fork Edisto Rivers. The Savannah River bounds the reservation for 17 miles (27 km) on the southwest side of the site and is a major source of water for SRS operations. The site is entirely outside of the Edisto drainage basin, and only a small portion of the east end of the site is within the Salkehatchie drainage basin (Ref. 11).

GENERAL USES OF THE SAVANNAH RIVER

The Savannah River forms the boundary between Georgia and South Carolina. Downstream from Augusta, GA, the Savannah River has been classified as Class B waters suitable for domestic supply after treatment, propagation of fish, and industrial and agricultural uses. The river supplies water for Augusta, GA; North Augusta, SC; and Beaufort and Jasper Counties, South Carolina; and supplements the water supply of Savannah, GA. It also receives domestic and industrial wastes from Augusta, GA; North Augusta, SC; and Horse Creek Valley (Aiken County, South Carolina).

At SRS, the coal-fired power plants are cooled with water pumped from the river. Effluents and wastewater from SRS are discharged into the Savannah River tributaries that flow across SRS.

Recreational uses of the Savannah River include boating and sport fishing, and a limited amount of contact activities such as swimming and water skiing.

NAVIGATION

During the early operation of the Thurmond and Hartwell Lakes (1953-1972), there was navigational traffic on the river from Augusta to Savannah. By the late 1970s, waterborne commerce was limited to the transportation of oil to Augusta. In 1979, this shipping was discontinued. Since that time, except for limited movements of construction-related items, no commercial shippers have used the river. Maintenance dredging of the river was discontinued in 1979 (Ref. 45, 46).

FISHERIES

Three types of fisheries are found along the Savannah River. Freshwater trout are in the cold waters flowing from the mountains of North Carolina, South Carolina, and Georgia. Other freshwater fish species are found in the warmer waters in the Piedmont and Coastal Plain; saltwater species are found downstream in the brackish waters near the mouth and in the estuary.

Warm water fishing constitutes most of the sport fishing in the Savannah River. According to a 1988 Savannah River creel study, the annual fish harvest from the river by sport fisherman is approximately 152,000 pounds of fish. The principal species harvested by sport fishermen were redbreast sunfish, bluegill, channel catfish, and crappie (Ref. 47).

Commercial fisheries are important to the economy of the coastal region of South Carolina and Georgia. The most important cash species are blue crabs and shad. South Carolina fishermen harvested 134,000 pounds of blue crabs from the Savannah River estuary in 1989 (Ref. 47). Shrimp, clams, and oysters are harvested commercially from the Savannah River estuary. The average South Carolina annual shrimp and clam harvests from the Savannah River estuary are estimated to be 76,000 pounds and 5,500 pounds, respectively. The annual average Georgia shrimp and clam harvests are approximately 616,000 pounds and 4,200 pounds, respectively. Oysters are also harvested from the Savannah River area at a rate of approximately 30,000 pounds annually (Ref. 47). Data on the commercial fish harvest in the Savannah River were provided by the SCDNR and the Georgia Department of Natural Resources.

RECREATION

Over 95% of South Carolina's impounded waters are contained in the large reservoirs listed in Table 1.3-18. Most have multipurpose recreational uses such as swimming, water skiing, boating, and fishing. Par Pond and L Lake, both previously used for reactor cooling water, are completely within the boundary of SRS and are not accessible to the public. Thurmond Lake (Clarks Hill Reservoir), Hartwell Reservoir, and Russell Dam are located northwest of Augusta approximately 65 to 133 river miles (104 to 213 river km) from the center of the site. They are used for hydroelectric power generation, flood control, and water supply, as well as for recreation. There were more than 22 million visitors to Thurmond Lake, Hartwell Reservoir, and Russell Dam during fiscal year 1986 (Ref. 45).

Numerous multipurpose small lakes and ponds are found in Georgia and South Carolina counties adjacent to SRS. Lakes and ponds 10 acres or larger are listed in Table 1.3-19 for Aiken, Allendale, and Barnwell Counties, South Carolina, and in Table 1.3-20 for Burke, Richmond, and Screven Counties, Georgia.

Boat use on the Savannah River is estimated based on boat registrations. In 1993, there were 280,894 boats registered in South Carolina. Of these, 25,021 were registered in South Carolina counties bordering the Savannah River south of Augusta. Most of the boats for this section of the Savannah River were registered near Augusta and Thurmond Lake in Aiken County (9,841) and in Beaufort County (9,381) near the coast. Fewer boats were registered for Barnwell (1,783), Allendale (628), Hampton (2,076), and Jasper (1,312) Counties. Most of the boats registered for the counties along this part of the Savannah River were registered near Augusta and Thurmond Lake in Richmond County (6,350) and in Chatman County (12,424) near the coast. Fewer boats were registered in Burke (811), Screven (1037), and Effingham (2,757) Counties. Public boat landings on the Savannah River downstream from Augusta are listed in Table 1.3-21 for South Carolina and Georgia.

AGRICULTURAL WATER USE

Water for agricultural use in Aiken, Barnwell, and Allendale Counties is obtained primarily from lakes and ponds. Capabilities of existing sprinkler irrigation systems in these three counties are given in Table 1.3-22. Corn, peanuts, soybeans, and truck crops are the crops for which irrigation is economically feasible (Ref. 48). In Burke County, Georgia, there are approximately 225 irrigation systems with a combined capacity of 25,000 acres. Richmond County, Georgia, has seven irrigation systems with a combined capacity of 1,200 acres.

No uses of the Savannah River for crop irrigation were identified in Richmond and Burke Counties, Georgia, or for Aiken, Barnwell, and Allendale Counties, South Carolina.

MUNICIPAL USE OF LOCAL SURFACE WATER

The Savannah River and its reservoirs are the sources of water for 64 domestic and industrial users. Total withdrawals amount to approximately 1 billion gallons per day. The largest water users are SRS and VEGP. At the lower end of the river, freshwater intakes and canals are maintained by the Beaufort-Jasper Water Supply Authority, the City of Savannah Municipal and Industrial Plant, and the Savannah National Wildlife Refuge (Ref. 45).

The larger communities in Aiken, Richmond, and Burke Counties use surface water supplies as well as groundwater. None of these surface water supplies are impacted by liquid discharges from operations at SRS. These intakes are all either on the Savannah River upstream from SRS or on tributaries of the Savannah River that do not cross or drain at SRS.

In Aiken County, the City of Aiken uses water from Shaws Creek. The Graniteville Company provides water to Graniteville and Vaucluse from Horse Creek, Bridge Creek, and Good Springs. The Clearwater Water District supplies approximately 3.2 million gallons per day (mgd) from Little Horse Creek. The city of North Augusta draws about 2.78 mgd from the Savannah River. Surface water supplies for Aiken County are shown in Table 1.3-23.

In Richmond County, the Augusta city water system draws its water supply, averaging about 24 mgd, from the Savannah River at a point more than 25 miles (40 km) upstream from SRS.

Waynesboro, the largest user in Burke County, draws water from Briar Creek and from groundwater. Surface water use by these two counties in Georgia is shown in Table 1.3-24. Columbia County, Georgia, is currently constructing a surface water plant along Georgia Route 50 to withdraw water from Thurmond Lake.

MUNICIPAL AND INDUSTRIAL USE OF SAVANNAH RIVER WATER DOWNSTREAM FROM SAVANNAH RIVER SITE

There are two water treatment plants about 100 miles (160 km) downriver from SRS that supply Savannah River water to customers in Beaufort and Jasper Counties, South Carolina, and Chatham County, Georgia. The City of Savannah Industrial and Domestic Water Supply (Chatham County, Georgia) is the largest of the two water treatment plants (Table 1.3-25).

The Beaufort-Jasper Water/Sewer Authority near Hardeeville, SC has been in operation since 1965. It serves a consumer population of about 50,000 people who live in Beaufort and Jasper Counties. The plant is located about 18 miles (29 km) from the Savannah River. A canal transports water from the river to the plant. The plant processes an average of 6 mgd, varying from about 5 mgd in the winter to 10 to 12 mgd in the summer. Increased use in the summer is associated with watering lawns, filling swimming pools, and uses in the home (Ref. 48).

The City of Savannah Industrial and Domestic Water Supply at Port Wentworth has been treating water during the entire period of operation of SRS. Treated water from this plant is used primarily for industrial and manufacturing purposes in an industrial complex near Savannah, GA.

The complex serves a non-community/non-transient population of 6,000 people, primarily adults working in industrial facilities; it also serves as a backup for the City of Savannah's domestic groundwater system. The plant processes about 40 to 50 mgd. Usage of this water for the City of Savannah does not show a strong summer demand, since the water is primarily used for industrial purposes.

GROUNDWATER USE

The coastal plain sediments that underlie SRS are an important hydrologic resource, since the formations are sources for drinking water, industrial processes, and cooling water, and water used for agricultural purposes. Fifty-six municipalities and industries identified near the site use this groundwater. Total pumpage by these users in 1985 was approximately 35 mgd. In addition, several small communities, mobile home parks, schools, and small commercial interests draw from this groundwater resource (Ref. 11).

1.4 ENVIRONMENTAL DESCRIPTION

1.4.1 METEOROLOGY

Information on SRS meteorological conditions is primarily taken from Hunter with supplemental data from the National Oceanic and Atmospheric Administration Local Climatological Data (Ref. 49-52).

1.4.1.1 Regional Climatology

The SRS region has a humid subtropical climate, characterized by relatively short, mild winters and long, warm, and humid summers.

Summer weather usually lasts from May through September, when the area is subject to the influence of the western extension of the semipermanent Atlantic subtropical anticyclone (the "Bermuda high" pressure system). As a result, winds are generally light and weather associated with low pressure systems and fronts usually remains well to the north of the area. Because the Bermuda high is a persistent feature, there are few breaks in the summer heat. High temperatures during the summer months are greater than 90°F on more than half of all days (Ref. 49). The relatively high heat and humidity often result in scattered afternoon and evening thunderstorms.

The influence of the Bermuda high begins to diminish during the fall, resulting in drier weather and temperatures that are more moderate. Average rainfall for the fall months is lower than average for the other months of the year. Frequently, fall days are characterized by cool, clear mornings and warm, sunny afternoons. Average daily temperatures during the fall months range from 76°F to 50°F.

During the winter, migratory low pressure systems and associated fronts influence the weather of SRS. Conditions frequently alternate between warm, moist, subtropical air from the Gulf of Mexico region and cool, dry, polar air. Occasionally, an arctic air mass will influence the area; however, the Appalachian Mountains to the north and northwest of SRS moderate the cold temperatures associated with the polar or arctic air. Consequently, less than one-third of the winter days have minimum temperatures below freezing, and temperatures below 20°F are infrequent.

Spring is characterized by a higher frequency of occurrence of tornadoes and severe thunderstorms than the other seasons of the year. This weather is often associated with the passage of cold fronts. Although weather during the spring is variable and relatively windy, temperatures are usually mild.

ICE AND SNOW

Snow and ice storms in the region occur very infrequently. Snowfalls of 1 inch or greater occur once every 3 years on the average. Furthermore, any accumulation of snow rarely lasts for more than 3 days (Ref. 52).

The greatest single snowfall recorded in the SRS area (Augusta) during the period 1951-1995 occurred in February 1973. This storm produced a total of 14.0 inches of accumulation, including 13.7 inches in a 24-hour period. A summary of maximum total snowfalls for 24-hour and monthly periods, observed at the National Weather Service (NWS) office at Augusta, GA, is given in Table 1.4-1 (Ref. 52). The maximum ground snow load for the SRS area for a 100-year recurrence period is estimated to be about 5 lb.-force/ft^2 (Ref. 49).

For a 9-year period of record reported by Tattelman (Ref. 53), storms resulting in an accumulation of ice on exposed surfaces occurred in the SRS area an average of about once every 2 years. Average ice accumulations for various recurrence intervals for a region that includes SRS and consists of the Gulf Coast states are given in Table 1.4-2. The 100-year recurrence ice storm is estimated to produce an accumulation of approximately 0.67 inches (Ref. 53).

SURFACE WIND PATTERNS AND DISPERSION CLIMATOLOGY

A meteorological database for the 5-year period 1992-1996 is currently used for safety analysis at SRS. Wind rose plots for each of the eight SRS towers for this period of record are shown in Figures1.4-1 through 1.4-10. As indicated by these plots there is no strongly prevailing wind direction at the Site. Northeasterly winds occurred approximately 10% of the time, and west to southwest winds occurred about 8% of the time. Winds at D-Area exhibited slightly higher frequencies of southeast and west-northwesterly winds due to the effects of the terrain that defines the Savannah River valley. Annual average wind speeds at each of the towers ranged from 9.4 mph (4.2 m/s) to 8.0 mph (3.5 m/s).

The relative ability of the atmosphere to disperse air pollutants is commonly characterized in terms of Pasquill stability class. The Pasquill stability classes range from class A (very unstable conditions characterized by considerable turbulence producing rapid dispersion) to class G (extremely stable conditions with little turbulence and very weak dispersion). The percent occurrence of Pasquill stability class for each of the eight area towers is summarized in Table 1.4-3. Stable conditions were observed between 20 and 30 percent of the time during the 5-year report. Wind rose plots by stability class for each tower are shown in Figures 1.4-1 through 1.4-9 (Ref. 51).

THUNDERSTORMS

An average of about 54 thunderstorm days per year was observed in the SRS area during the period 1951-1995. Average thunderstorm days per month are listed in Table 1.4-4. Fifty percent of the annual average total occurred in June, July, and August. Thunderstorm occurrence was least frequent during the months of October through January, with an average of about one day per month observed (Ref. 49).

The occurrence of hail with thunderstorms is infrequent. Based on observations in a 1-degree square of latitude and longitude that includes SRS, hail occurs once every 2 years on the average (Ref. 54).

The frequency of cloud-to-ground lightning strikes has been estimated using an empirical relationship described by Marshall (Ref. 55).

The estimated average number of lightning strikes per square kilometer (km^2) per year is given by:

$$NE = [0.1 + 0.35 \sin(l)]A \qquad \text{(Eq. 1.4-1)}$$

where:

NE = the number of flashes to earth/km^2/thunderstorm day

l = the latitude of the approximate geographic center of SRS (33°16')

A = given by (0.4 +/- 0.2)

Assuming the most conservative value for A (0.6), the number of flashes to earth per square kilometer was estimated to be ten per year. Measurements of cloud-to-ground lightning strikes recorded from the National Lightning Detection Network over the 5-year period 1989-1993 show an average of four strikes per square kilometer, per year in the SRS area (Ref. 56).

TORNADOES

Weber, et al, (Ref. 57) identified a total of 165 tornadoes occurring within a 2-degree square of latitude and longitude (2° by 2°) centered on SRS over a thirty-year period from 1967. Tornado occurrence by month and Fujita (F)-scale intensity category since 1951 is summarized in Table 1.4-5. About half of the total number of observed tornadoes occurred in the months of March, April, May, and November; however, tornadoes have been observed in the SRS region every month of the year.

Nine tornadoes have occurred on or in close proximity to the SRS since operations began in the 1950s. A tornado that occurred on October 1, 1989 knocked down several thousand trees over a 16-mile path across the southern and eastern portions of the site. Wind speeds produced by this F2 tornado were estimated to be as high as 150 mph. Four F2 tornadoes struck forested areas of SRS on three separate days during March 1991 (Ref. 58). Considerable damage to trees was observed in the affected area. The other four confirmed tornadoes were classified as F1 and produced relative minor damage. None of the nine tornadoes caused damage to buildings.

Estimates of the expected tornado wind speeds that are exceeded at SRS for various return frequencies are summarized in Table 1.4-7. These estimates were determined from a tornado wind hazard model developed by Lawrence Livermore National Laboratory (LLNL) (Ref. 501). The LLNL tornado wind hazard model is given by:

$$EF(v) = \lambda \Sigma_i \{\Sigma_{j\leq i} P(WS>v|Fj,Fi) \int_{\theta} \int_{(L,W)i} \int_{A(Sij)} dF(x,y)dH(L,W)\, dG(\theta)\}\{\Sigma_k p_{ik} P_R(Fk)]$$

Where λ is the expected frequency of a tornado occurring anywhere in the contiguous United States, P(WS>v|Fj,Fi) is the conditional probability that the wind speed is greater than v mph for a tornado with Fujita-scale intensity Fj within the damage area of an Fi intensity tornado, dF(x,y) is a tornado touchdown location density function for the site-specific area, dH(L,W) is a damage area density function for tornado damage paths of length L and width W, and dG(θ) is a density function of tornado path headings with direction θ. The expected frequency of tornado occurrence, λ, is determined from the NOAA *Storm Prediction Center* (SPC) tornado database for the period 1950-1995.

The conditional probability P(WS>v|Fj,Fi) is evaluated by generating a site-specific tornado F-scale intensity distribution (F0 through F6), using the historical database from SPC, for each of three areas centered on SRS: a 2^{o} by 2^{o} area, a 3^{o} by 3^{o} area and a 5^{o} by 5^{o} area. Each area is assigned a weight representing the uncertainty that data from the area provides a 'true' characterization of tornado intensity at the location of interest. The resulting F-scale intensity distributions are transformed to histograms expressing the frequency of occurrence of wind speed intervals that correspond to each of the seven intensity categories. Histograms are constructed for three methods of relating F-scale intensity to wind speed. For each of the three discreet wind speed distributions, maximum likelihood estimation techniques are used to determine which of three continuous distribution functions (uniform, beta, and Weibull) best fit the wind speed data. The selected distribution function is used to determine an occurrence probability for each wind speed interval which is subsequently transformed to an estimated theoretical 'recorded' F-scale intensity distribution $P_R(F_i)$. The term $\Sigma_k p_{ik} P_R(Fk)$ is then evaluated to adjust P_R for misclassification error described by the probability matrix p_{ij}. The five misclassification matrices that are employed by the model include both random error and direct classification error as identified in the literature. The result consists of 45 estimates of the F-scale intensity distributions, with associated weights for use in developing uncertainty estimates.

The LLNL model assumes that the location for hazard prediction is an area and that there is a non-uniform distribution of touchdown location within the region of interest. A tornado touchdown location density function, dF(x,y) is defined and integrated over area A(Sij) with respect to the probability distributions of the variables that define A(Sij), namely dG and dH. The area A(Sij) denotes the tornado effect subarea of intensity Fj within a tornado of intensity Fi (where index $j \leq i$). The location density function dF(x,y) is given by a normal kernel estimator which predicts the areal distribution of future tornado locations based on the historical database. The distribution of tornado heading dH also is determined from the historical database; but the model allows selection of one of three sets of empirical distributions weighted by the time period of data collection and geographic location. The damage area density function, dG, consists of a joint distributions of damage path lengths and widths by F-scale intensity as determined from the historical data. Uncertainty weights are assigned to each of the time-dependent distributions.

Final estimates of wind speed for a given return interval are determined by conducting 125 simulations of the tornado model. For each simulation, Latin Hypercube sampling techniques are used to select values for each of the stochastic variables including tornado heading, length and width, intensity and location. The estimated wind speed for each of the return intervals, summarized in Table 1.4-7, represents a mean of the resulting set of wind speed values.

PC3 and PC4 design basis tornado speeds are shown in Table 1.4-7.1.

ATMOSHERIC PRESSURE CHANGE

The tornadic atmospheric pressure change effects including the maximum rate thereof for various tornado speeds are calculated in an engineering calculation (Ref. 503). The PC3 and PC4 design basis atmospheric pressure change and the rate thereof, shown in Table 1.4-7.1, are taken as the rounded values corresponding to the tornado speeds of 180 and 240 mph, respectively.

EXTREME WINDS

Extreme winds in the SRS area, excluding tornado winds, are associated with tropical weather systems, thunderstorms, or strong winter storms. Extreme fastest 1-minute wind speeds for the 30-year period 1967-1995 are summarized in Table 1.4-8. These data were recorded at the National Weather Service Office at Augusta, GA (Ref. 52). The maximum 1-minute wind speed observed during the entire period of record at Augusta was 83 mph in May 1950.

Estimates of an expected maximum 'straight-line' (nontornadic) wind speeds (three second gust) for any point on the Site for return periods from 100 to 100,000 years are summarized in Table 1.4-7 (Ref. 57). These estimates were generated from a Fisher-Tippet Type I extreme value distribution function using historical wind speed (gust) data from the SRS meteorological database and from nearby National Weather Service stations (Columbia, SC, and Augusta, Macon, and Athens, GA). For each observing station, a maximum observed annual gust was determined for each year in the available period of record. The period of record ranged from 25 to 47 years. The resulting subsets of annual wind speed maxima were used to determine a best fit to one of three types of a generalized extreme value (GEV) distribution. The analysis indicated that a Fisher-Tippet Type I (Gumbel) distribution was appropriate for these data.

Following a method suggested by Eliasson (Ref. 502), the predicted 3-second wind speed for return period P is given by:

$$X_P = [S\{(0.8 - 0.57722)/1.28255\} + X][[1 + (0.78 / \{(1/CV_a) + 0.72\}][\log\{-\log(1(1-1/P))\} - 1.5]$$

Where X is the average of the annual observed wind speed maxima at the station of interest (Augusta, Ga), S is the standard deviation of the annual wind speed maxima for the station of interest, and CV_a is the average coefficient of variation for all stations included in the analysis.

PC3 and PC4 design basis wind speeds are given in Table 1.4-7.1.

MISSILES

The design basis straight-line wind and tornado missiles, except for the PC3 tornadic automobile missile, are based on the DOE-STD-1020 (Ref. 504) requirements for PC3 and PC4 DOE sites. The PC3 tornadic automobile missile is based on the recommendation of McDonald-Mehta (Ref. 505). McDonald (Ref. 506) provides the rationale for the PC3 and PC4 design basis missile speeds in relation to the observed data for tornado and results of simulation studies, and observes that these are different from the U. S. NRC criteria for nuclear power plants. The design basis missile criteria are given in Table 1.4-7.1.

HURRICANES

A total of 36 hurricanes have caused damage in South Carolina over the 290-year period from 1700-1992. The average frequency of occurrence of a hurricane in the state is once every 8 years; however, the observed interval between hurricane occurrences has ranged from 2 months to 27 years. The percentages of hurricane occurrences by month in South Carolina are given in Table 1.4-9. Approximately 80% of hurricanes in South Carolina have occurred in August and September.

Because SRS is approximately 100 miles (160 km) inland, winds associated with tropical weather systems usually diminish below hurricane force (sustained speeds of 75 mph (120 km/h) or greater). However, winds associated with Hurricane Gracie, which passed to the north of SRS on September 29, 1959, were measured as high as 75 mph (120 km/h) on an anemometer located in F Area. No other hurricane-force wind has been measured on the site. On September 22, 1989, the center of Hurricane Hugo passed about 100 miles (160 km) northeast of SRS. The maximum 15-minute average wind speed observed onsite during this hurricane was 38 mph (61 km/h). The highest observed instantaneous wind speed was 62 mph (100 km/h). The data were collected from the onsite tower network (measurements taken at 200 feet [60 meters] above ground). Extreme rainfall and tornadoes, which frequently accompany tropical weather systems, usually have the most significant hurricane-related impact on SRS operations (Ref. 49).

EXTREME PRECIPITATION

Maximum observed rainfall recorded at Augusta's Bush Field and the Columbia, SC airport for various accumulation periods is summarized in Table 1.4-10 (Ref. 51, 60). These data were based on a 48-year period of record (1948-95).

Estimates of expected maximum rainfall at SRS for rainfall durations of 15-minutes to 24 hours and return periods from 10 years to 100,000 years are shown in Table 1.4-11 (Ref. 57, 61). These estimates were based on a statistical analysis of hourly rainfall from eight National Weather Service first-order and cooperative stations (Augusta, Macon, Athens, Sylvania, and Louisville in Georgia and Columbia, Wagener, and Clark Hill in South Carolina), 15-minute rainfall from three of the cooperative stations (Sylvania, Louisville, and Wagener), and daily rainfall from four rain gages at SRS. Stations were selected based on proximity to and geographic similarity with the SRS. For each station (as appropriate to the data set), a annual maximum observed rainfall for each of the six duration intervals of interest over the available period of record were determined. The period of record ranged from 25 to 47 years. The resulting subsets of annual wind speed maxima were used to determine a best fit to one of three types of a generalized extreme value (GEV) distribution.

The analysis indicated that a Fisher-Tippet Type I (Gumbel) distribution was appropriate for the 15-min and 1-hour datasets. Following a method suggested by Eliasson (Ref. 502), the predicted rainfall for return period P is given by:

$$X_P = [S\{(0.8 - 0.57722)/1.28255\} + X][[1 + (0.78 / \{(1/CV_a) + 0.72\}][\log\{-\log(1(1-1/P))\} - 1.5]$$

Where X is the average of the annual observed maxima rainfall at the station of interest (Augusta, Ga for the 1-hour duration rainfall and Sylvania, Ga for 15 minute rainfall), S is the standard deviation of the annual rainfall maxima for the station of interest, and CV_a is the average coefficient of variation for all stations included in the analysis.

A Fisher-Tippet Type II distribution was found to provide the best fit for the 3, 6, 12, and 24 hour rainfall data. The corresponding predicted rainfall for return period P is given by

$$X_P = X + S\{\beta + (a/k)(1-[-\log(1-1/P]k)\}$$

Where X and S are determined from the observed annual maxima for Augusta, and the distribution parameters a, b, and k are calculated from the annual maxima for all of the stations that were included in the analysis.

Several significant rainfall events occurred at SRS in the summer and fall of 1990 (Ref. 60). Table 1.4-11 includes the observed rainfall totals from those storms that exceeded the predicted extreme rainfall values. Short duration extreme rainfalls are generally produced by spring and summer thunderstorms. Longer duration extreme rains are usually produced by the remnants of tropical weather systems.

EXTREME AIR POLLUTION EPISODES

High air pollution potential in the southeastern U.S. is frequently associated with stagnating anticyclones (high pressure systems). According to routine radiosonde (upper air) data summarized by Holzworth, episodes of poor dispersion conditions in the SRS area lasted for 2 days on twelve occasions over a 5-year period (1960-1964) (Ref. 62). Episodes lasting at least 5 days occurred on two occasions. An episode is defined by mixing heights less than 5,000 feet (1,525 m) and average boundary layer wind speeds less than 9 mph (14.5 km/h). Results of a study reported by Korshover indicate that an average of two air stagnation episodes occurred in the SRS area each year over the 40-year period from 1936 to 1975 (Ref. 63). The total number of stagnation days averaged about 10 per year. Korshover defined stagnation days as conditions characterized by limited dispersion lasting 4 days or more (Ref. 63).

1.4.1.2 Local Meteorology

DATA SOURCES

A number of sources of data are used to describe the local climatology. These include eight meteorological towers adjacent to the major operations areas onsite, the Central Climatology Meteorological Facility located near N Area, a meteorological instrument shelter in A Area, and the NWS office at Bush Field in Augusta, GA. The NWS office at Augusta is approximately 12 miles (19 km) west-northwest of SRS. Locations of the onsite towers are shown on Figure 1.4-10.

The eight area towers are equipped with fast-response cup anemometers, bi-directional wind vanes (bivanes), slow response resistance temperature probes, and lithium chloride dew point sensors at a height of 38 feet (61 meters) above ground. The Central Climatology Facility tower is equipped with identical instrumentation at elevations of 4, 18, 36, and 61 meters. Central Climatology is also equipped with instrumentation for measuring precipitation, evaporation, solar radiation, barometric pressure, and soil temperature. Data collected at the A-Area instrument shelter consist of temperature, daily precipitation, and relative humidity. Parker and Addis (Ref. 64) provide a computer description of SRS Meteorological Monitoring Program.

Summaries of temperature, precipitation, and relative humidity are based on a composite data set consisting of data from the instrument shelter through 1994 and from Central Climatology for 1995 and 1996.

TEMPERATURE

Monthly and annual average temperatures for SRS for the 30-year period 1967-1996 are included in Table 1.4-12. At SRS, the annual average temperature is 64.7°F. July is the warmest month with an average daily high temperature of 92.1°F and an average daily low temperature of 71.5°F. January is the coldest month with an average daily high temperature of 55.9°F and an average daily low temperature of 36.0°F. Observed temperature extremes for SRS over the period 1961-1996 ranged from 107°F to -3°F.

Data for Augusta, GA indicate that prolonged periods of cold weather seldom occur. Daytime high temperatures during the winter months are rarely below 32°F. Conversely, high temperatures in the summer months are above 90°F on more than half of all days. The average dates of the first and last freeze are November 12 and March 16, respectively (Ref. 52).

PRECIPITATION

Annual average precipitation for SRS over the 30-year period 1967-1996 is 49.5 inches (see Table 1.4-13). Precipitation is fairly evenly distributed throughout the year. Average precipitation for the fall months (September, October, and November) is less than that for the other seasons, accounting for about 20% of the average annual total. For Augusta, precipitation totals greater than 0.01 inch occur on an average of about 108 days per year. The average number of days per month with measurable precipitation ranges from about 6 days in October to about 12 days in July (Ref. 52).

Monthly precipitation extremes for SRS range from a maximum of 19.62 inches, recorded in October 1990, to a trace observed in October 1963. The greatest observed rainfall for a 24-hour period was 7.5 inches in October 1990 (Ref. 60). Hourly observations at Augusta indicate that rainfall rates are usually less than 0.5 in./h, although rainfall rates of up to 2 in./h can occur during summer thunderstorms (Ref. 52).

A summary of snowfall statistics for Augusta (1951-1995) is shown in Table 1.4-1. The average annual snowfall for the SRS area (Augusta) for the period 1966-1995 was 1.1 in./year, and the average number of days per year with snow was 0.6 day. Significant snowfall is most likely to occur in February. For the reported period of record, snow has been observed during all of the months November through March.

HUMIDITY

Monthly and annual values of relative humidity for SRS (1967-1996) are given in Table 1.4-14. Average relative humidities are highest in August (ranging from an average of 97% in the morning to 50% in the afternoon) and lowest in April (ranging from an average of 88% in the morning to 36% in the afternoon).

Table 1.4-14 also summarizes monthly and annual average absolute humidities from the Central Climatology station for the 2-year period 1995-96. The annual average humidity was 11.1g/m^3. Monthly average values range from 18.4 g/m^3 in July to 6.0 g/m^3 in December and January (Ref. 50).

FOG

Heavy fog (reducing visibility to less than 1/4 mile) occurred at the Augusta NWS office on an average of about 30 days per year during the period 1951-1995 (Ref. 52). Occurrences averaged about 3 days per month during the fall and winter months and slightly more than 1 day per month during the spring and summer months. Most of the heavy fog observed at Augusta is due to the proximity of the Savannah River. Fog is observed less frequently at the SRS because the site is at a higher elevation than Augusta and is further from the river (Ref. 49).

MIXING HEIGHT

The mixing height is the level of the atmosphere below which pollutants are easily mixed; it is often equal to the base of an elevated inversion. The following estimates of seasonally averaged morning mixing heights for SRS were interpolated from data presented in Holzworth (Ref. 62). The Holzworth data are derived from radiosonde observations during the 5-year period, 1960-1964.

	Mixing Height (meters)	
Season	Morning	Afternoon
Winter	1148	3362
Spring	1230	5576
Summer	1312	5904
Fall	984	4592
Annual	1230	4756

LOW-LEVEL INVERSIONS

In 1961, Hosler analyzed 2 years of radiosonde and surface observations of the NWS to determine occurrence frequencies for low-level inversions in the U.S. Hosler's statistics show that inversions occur in the SRS area approximately 40% of all hours and 70% of all night hours (Ref. 65).

Pendergast analyzed temperature data collected from sensors located on multiple levels of the WJBF television tower for a 1-year period (1974) (Ref. 66). The WJBF tower is located approximately 9 miles (14 km) northwest of SRS. For approximately 30% of the time, an inversion extended through the entire 10- to 1,099-foot layer for which temperature measurements were made. For about 12% of the time, an inversion was observed through the upper portion of the 10- to 1,099-foot layer, and unstable conditions were observed through the lower portion. For about 9% of the time, the ground-based inversion layer height was less than the height of the tower. The latter two cases generally were found to represent the transition periods from night to day and from day to night, respectively.

TOPOGRAPHY

The topography of the SRS area is characterized by gently rolling, forested hills. In general, terrain elevations decrease gradually from the Appalachian foothills northwest of the site toward the Atlantic coastal plain to the southeast. The local SRS terrain elevations also generally decrease gradually toward the Savannah River, which runs along the southwestern boundary of the site. Site elevations range from 100 feet to about 400 feet above msl. A topographic map of SRS and the surrounding area is shown in Figure 1.3-5.

The closest pronounced topographic feature is approximately 20 miles (32 km) from the site; the local terrain has little effect on wind and stability climatology at SRS. During stable atmospheric conditions, some channeling or airflow stagnation could occur in some of the more pronounced valleys. However, any terrain-induced increase in pollutant concentrations would be much localized and short-lived.

1.4.1.3 Onsite Meteorological Measurement Program

The current meteorological monitoring program at SRS meets or exceeds criteria in Environmental Regulatory Guide DOE/EH-0173T, Safety Guide 23 of the NRC, Guide 2.5 of the American Nuclear Society, and the Environmental Protection Agency (EPA), as reported by Parker and Addis (Ref. 64). The instrumentation used to collect the meteorological data is summarized in Section 1.4.1.2.

A data logger at each monitoring tower collects a reading from each instrument every 1.5 seconds. The instantaneous data are processed and used to compute 15-minute and hourly averages of wind speed, wind direction (vector and scalar), temperature, and dew point. In addition, the 15-minute and hourly values of sigma-a and sigma-e (the standard deviation of the fluctuations of the horizontal and vertical component of wind direction, respectively) are calculated. The 15-minute data are then transmitted via a dedicated telephone line to a central computer system and archived in a relational database.

Real-time emergency response applications are the primary considerations in the operation of the monitoring network. Consequently, the data are inspected daily, so any major system malfunction can be corrected on a timely basis. An adequate supply of spare calibrated instrumentation is maintained so replacement sensors are readily available.

The instrumentation is calibrated every 6 months by SRTC instrument mechanics. A wind tunnel at SRTC is available for calibration of the wind sensors. The calibrations are conducted according to manufacturer's specifications using procedures that meet or exceed American Society of Testing and Materials (ASTM) calibration methods (Ref. 64).

Data collected from the meteorological towers are stored in a relational database and retrieved, as necessary, to develop quality assured databases for engineering, safety, and regulatory applications. A 5-year database for the period 1991-1996 is currently used for SRS SARs. The development of this database is described by Kurzeja (Ref. 67).

ONSITE AIR QUALITY

The South Carolina Department of Health and Environmental Control (SCDHEC) regulates nonradioactive air emissions, both criteria pollutants and toxic air pollutants, from SRS sources. Each source is permitted by SCDHEC, with specific limitations identified, as outlined in various South Carolina air pollution control regulations and standards. Results of the most recent regulatory compliance modeling for SRS emissions are summarized in the SRS Annual

Environmental Report (Ref. 20). A list of the SCDHEC-issued air quality permits and a description of the Airborne Emissions programs are in the SRS Annual Environmental Report.

USE OF METEOROLOGY DATA

The meteorology data are used to estimate the meteorological dispersion of released materials as discussed in Section 3.1, Methodology, in Chapter 3 of the SAR for the specific facility. A description of many of the calculational codes in use is given in the WSRC Environmental Dose Assessment Manual (Ref. 68).

1.4.2 HYDROLOGY

1.4.2.1 Surface Hydrology

HYDROLOGIC DESCRIPTION

Much of SRS is located on the Aiken Plateau (see Figure 1.4-11). The plateau slopes to the southeast approximately 5 feet per mile (1 m/km). The plateau is dissected by streams that drain into the Savannah River. The major tributaries that occur on SRS are Upper Three Runs Creek, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs Creek (see Figure 1.4-12). Beaver Dam Creek, the smallest of the six SRS tributaries of the Savannah River, is located north of Fourmile Branch, primarily in the floodplain of the Savannah River. Tinker Creek and Tims Branch are tributaries of Upper Three Runs Creek; Indian Grave Branch is a tributary of Pen Branch. Each creek originates on the Aiken Plateau and descends 49 to 200 feet (15 to 61 meters) before discharging to the Savannah River. The interstream upland area is flat to gently rolling and is characterized by gently dipping units of sand, sandy clay, and clayey sand.

The Savannah River is the principal surface-water system near SRS. The river adjoins the site along its southwestern boundary for a distance of about 20 miles (32 km) and is 140 river miles (225 river km) from the Atlantic Ocean.

The Savannah River cuts a broad valley approximately 250 feet deep through the Aiken Plateau (see Figure 1.4-13). Pleistocene coastal terraces lie between the Savannah River and the Aiken Plateau. The lowest terrace is the Savannah River floodplain, which is covered with a dense swamp forest. Higher terraces rise successively from the river floodplain to the Aiken Plateau and have a level to gently rolling topography.

The Savannah River Swamp lies in the floodplain along the Savannah River for a distance of about 10 miles and averages about 1.5 miles wide (see Figure 1.4-12). A small embankment or natural levee has built up along the north side of the river from sediments deposited during periods of flooding. The top of the natural levee is approximately 3 to 6 feet above the river during normal flow (river stage 85 feet) at the SRS boat dock. Three breaches in this levee (at the confluences with Beaver Dam Creek, Fourmile Branch, and Steel Creek) allow discharge of stream water to the river. During periods of high river level (above 88 feet), river water overflows the levee and stream mouths and floods the entire swamp area. The water from these streams mixes with river water and then flows through the swamp parallel to the river and combines with the Pen Branch flow. The flows of Steel Creek and Pen Branch converge 0.5 miles above the Steel Creek mouth. However, when the river level is high, the flows are diverted parallel to the river across the offsite Creek Plantation Swamp; ultimately they join the Savannah River flow near Little Hell Landing.

Surface water is held in artificial impoundments and natural wetlands on the Aiken Plateau. Par Pond, the largest impoundment on SRS, is an artificial lake located in the eastern part of the site that covers approximately 2,700 acres. A second large artificial impoundment, L Lake, lies in the southern portion of SRS and covers approximately 1,000 acres. Water from both Par Pond (200 feet) and L Lake (190 feet) drains to the south via Lower Three Runs Creek and Steel Creek, respectively, into the Savannah River. Water is also retained intermittently in natural lowland and upland marshes and natural basins, some of which are Carolina bay depressions (Ref. 69, 70).

The source of most of the surface water on SRS is either natural rainfall, which averages 48 inches annually, water pumped from the Savannah River and used for cooling site facilities, or groundwater discharging to the surface streams. Cooling water is discharged to streams that flow back to the Savannah River, L Lake, or Par Pond. Small volumes of water are also discharged from other SRS facilities to the streams.

The flow data used for computing statistics for the Savannah River and SRS streams were obtained from U.S. Geological Survey (USGS) stream measurement data. The data set consisted of daily average flows with varying periods of record (from 2 to 81 years) for SRS streams and the Savannah River.

Several flow statistics were derived from this data set over the period of record: daily minimums, maximums, and means; average flow; 7-day low flow, and the 7-day flow with a 10-year recurrence interval (7Q10) flow. The sampling locations are shown in Figure 1.4-14. Emphasis was placed on low flow statistics because disposal of wastes and maintenance of conditions for aquatic life are usually based on some type of low flow statistic. The seven-day low flow is widely used and is less likely to be influenced by minor disturbances upstream than is the minimum daily flow. The 7Q10 flow is a measure of the dependability of flow. The 7Q10 flow is derived from the frequency curve of the yearly 7-day low flow statistics over the period of record at that stream or river location. The Log Pearson Type III distribution statistics are normally used for computation of low flows in natural streams. Other distributions may be more appropriate in streams that are not naturally driven (such as those where cooling water may be the dominant component of flow).

The Log Pearson Type III distribution was applied to all SRS stream locations where a 7Q10 was computed (a program equivalent to the USGS A193 for computing Log Pearson Type III distributions was used). The climatic year, April 1 to March 31, is used for calculation of low flow statistics. In the U.S., this period contains the low flow period for each year. Flow statistics are summarized in Table 1.4-15 (average flow, standard deviation, 7Q10, and 7-day low flow).

The Savannah River drainage basin has a total area of 10,600 square miles and forms the boundary between the States of Georgia and South Carolina. The total drainage area of the river encompasses all or part of 41 counties in Georgia, South Carolina, and North Carolina. The Savannah River Basin is located in three physiographic regions or provinces: the Mountain, the Piedmont, and the Coastal Plain.

The Mountain Province contains most of the major tributaries of the Savannah River, including the Seneca, Tugaloo, and Chattooga Rivers. The region is characterized by a relatively steep gradient ranging in elevation from about 5,497 to 1,000 feet, and includes 2,042 square miles (19%) of the total drainage basin. The Mountain Province lies in the Blue Ridge Mountains and has a bedrock composed of gneisses, granites, schists, and quartzites; the subsoil is composed of brown and red sandy clays. In this region, the Savannah River and its tributaries have the character of mountain streams with shallow riffles, clear creeks, and a fairly steep gradient. The streambed is mainly sand and rubble.

The Piedmont Region has an intermediate gradient with elevations ranging from 1,000 to 200 feet. This region includes 5,234 square miles (50%) of the total drainage basin. Soils in the Piedmont are primarily red, sandy, or silty clays with weathered bedrock consisting of ancient sediments containing granitic intrusions. The Piedmont is bordered by the Fall Line, an area where the sandy soils of the Coastal Plain meet the rocky terrane of the Piedmont foothills. The city of Augusta, Georgia, is located near this line. The Savannah River picks up the majority of its silt load in the Piedmont Region, and most of this silt load is deposited in the large reservoirs located in the Piedmont Region.

The Coastal Plain has a negligible gradient ranging from an elevation of 200 feet to sea level. The soils of this region are primarily stratified sand, silts, and clays. The Coastal Plain contains 3,366 square miles (31%) of the total Savannah River drainage area (10,681 square miles), and includes the city of Savannah, GA. In the Coastal Plain, the Savannah River is slow moving. Tidal effects may be observed up to 40 miles (65 km) upriver, and a salt front extends upstream along the bottom of the riverbed for about 20 miles (32 km).

Dredging operations on the Savannah River have been conducted by the U.S. Army Corps of Engineers between the cities of Savannah and Augusta, GA. This program, initiated in October 1958, was designed to dredge and maintain a 9-foot navigation channel in the Savannah River from Savannah to Augusta, GA. Sixty-one sets of pile dikes were placed to constrict the river flow, thereby increasing flow velocities, and 38,000 linear feet of wood and stone revetment was laid to reduce erosion on banks opposite from the dikes. In addition, the channel was dredged and 31 cutoffs were made, reducing the total river distance from Augusta to Savannah by about 15 river miles. The project was completed in July 1965; periodic dredging was continued to maintain the channel until 1985.

SRS is located in the Coastal Plain Province of the Savannah River, about 25 miles downstream of Augusta, GA. Construction of upriver reservoirs (Strom Thurmond, Richard B. Russell, Hartwell, Keowee, and Jocassee), and the New Savannah River Bluff Lock and Dam have reduced the variability of the river flow. Low flows in the Savannah River typically occur during the autumn months while higher flows occur in late winter and early spring.

Upstream of SRS at Augusta, GA, the average flow for the 81-year period of record is 10,027 cfs. The average flow at Augusta, GA, since the filling of Thurmond Lake (Clarks Hill) has been 9,571 cfs (Table 1.4-15). Flows increase below Augusta, GA, to about 12,009 cfs near Clyo, GA, about 100 miles downriver (Table 1.4-15). The 7Q10 flow at Augusta, GA, is 3,746 cfs.

The peak historic flow for the 81-year period of record was 350,021 cfs in 1929. Since the construction of the upstream reservoirs, the maximum average monthly flow has been 43,867 cfs for the month of April.

Natural discharge patterns on the Savannah River are cyclic: the highest river levels are recorded in the winter and spring, and lowest levels are recorded in the summer and fall. Stream flow on the Savannah River near the site is regulated by a series of three upstream reservoirs: Thurmond, Russell, and Hartwell. These reservoirs have stabilized average, annual stream flow to 10,200 cfs near Augusta and 10,419 cfs at SRS.

The river overflows its channel and floods the swamps bordering the site when its elevation rises higher than 88.5 feet above msl (which corresponds to flows equal to or greater than 15,470 cfs). River elevation measurements made at the SRS Boat Dock indicate that the swamp was flooded approximately 20% of the time (74 days per year on the average) during the period from 1958 through 1967.

The Savannah River forms the boundary between the states of Georgia and South Carolina. Upstream of SRS, the river supplies domestic and industrial water needs for Augusta, GA, and North Augusta, SC. The river receives treated wastewater from these municipalities and from Horse Creek Valley (Aiken, SC). The Savannah River Class B waterway is used for commercial and sport fishing and pleasure boating downstream from SRS.

Water withdrawn from the river is used for various SRS activities, but is used primarily to cool the production reactors. The Savannah River downstream from Augusta, GA, is classified by the State of South Carolina as a Class B waterway, which is suitable for agricultural and industrial use, the propagation of fish, and after treatment, domestic use. The river upstream from the site supplies municipal water for Augusta, GA (river mile 187), and North Augusta, SC (river mile 201). Downstream, the Beaufort-Jasper Water Authority in South Carolina (river mile 39.2) withdraws water to supply a population of about 51,000. The Cherokee Hill Water Treatment Plant at Port Wentworth, GA (river mile 29.0) withdraws water to supply a business-industrial complex near Savannah, Georgia that has an estimated consumer population of about 20,000. It is estimated that each individual served by the two water treatment plants consumes an average of 1.3 liters of water per day. Site expansions for both systems are planned for the future.

SRS was once a major user of water from the Savannah River and withdrew a maximum of 920 cfs from the river. Currently, all SRS reactors are shut down, and river water withdrawals are minimal. Past operations typically removed about 9% of the average annual Savannah River flow, but river water usage averaged 0.133 cfs during the second quarter of 1995 (Ref. 71).

In 1995, DOE decided to discharge a minimum flow of 10 cubic feet (0.28 cubic meter) per second to Lower Three Runs Creek. Also to allow the water level in Par Pond to fluctuate naturally near its operating level (200 feet above msl) but not allowing the water level to fall below 195 feet. Additionally it was decided to reduce the flow to L Lake so long as the normal operating level of 190 feet was maintained and the flow in Steel Creek (downstream of L Lake) was greater than 10 cfs (Ref. 72).

Currently, only one of the pumps at pumphouse 3G is operated; it supplies 23,000 gallons per minute (gpm) (1.5 cubic meters per second), which is more than is needed for system uses. The excess water is discharged from reactor areas to Fourmile Branch, Pen Branch, L Lake, and the headwaters of Steel Creek. The preferred action by DOE is to eliminate the pumping of the excess water that is discharged to these streams.

The proposed shutdown of the river water system at SRS is addressed in a draft Environmental Impact Statement (EIS) (Ref. 73). The preferred action by DOE is to operate a small pump to supply 4,800 gpm of river water to L Area. The L-Area 186-basin would be maintained full for fire protection purposes. Overflow from the basin would provide blending for the L-Area sanitary wastewater discharge, keep L Lake at its normal operating level, and provide a minimum flow of 10 cfs to Steel Creek. Up to 200 gpm; this would eliminate C-Area discharges to Fourmile Branch (approximate average 265 gpm). Flows from K Area to Pen Branch would be expected to decrease from an average flow of 7,400 gpm to not more than 400 gpm. This flow would consist of overflow from the 186-basin and discharges of about 210 gpm from well-water-cooled compressors.

The river also receives sewage treatment plant effluents from Augusta, GA; North Augusta, Aiken, and Horse Creek Valley, SC; and other waste discharges along with the heated SRS cooling water via its tributaries. VEGP withdraws an average of 92 cfs from the river for cooling and returns an average of 25 cfs. The Urquhart Steam Generating Station at Beech Island withdraws approximately 261 cfs of once-through cooling water. Upstream, recreational use of impoundments on the Savannah River, including water contact recreation, is more extensive than it is near SRS and downstream. No uses of the Savannah River for irrigation have been identified in either South Carolina or Georgia.

The Beaufort-Jasper Water Authority in South Carolina (river mile 39.2) withdraws about 8 cfs to supply domestic water for a population of about 51,000. The Cherokee Hill Water Treatment Plant at Port Wentworth, GA (river mile 29.0) withdraws about 50 cfs from the river to supply a business-industrial complex near Savannah, which has an estimated consumer population of about 20,000.

Based on available information, the following sections describe surface hydrology in reference to specific local facilities.

F and E Areas

A topographic map showing surface drainage of F Area is shown in Figure 1.3-15. The F-Canyon building site is at an elevation of over 300 feet above msl. The nearest significant stream to F Canyon is Upper Three Runs Creek. It is located about 0.7 miles north and west of the F-Canyon facility. This creek flows at elevations below 150 feet. The mean annual flow at a gauging station approximately 3 miles from F-Canyon is 215 cfs. The measured maximum flow for the period 1974 to 1986 was about 950 cfs. Runoff from precipitation is diverted into storm sewers, then discharged to an unnamed tributary of Upper Three Runs Creek, which empties into the Savannah River.

Area surface water bodies near the SWMF consist of Fourmile Branch and Upper Three Runs Creek, and their tributaries. All drainage is to the Savannah River. There are no surface waters, including intermittent streams, within 2,000 feet of the SWMF, and the SWMF areas are not located in the flood-prone areas. The surface waters affected directly or indirectly by the SWMF and seepage basin outcropping from plumes caused by past operations are Fourmile Branch and the Savannah River, into which Fourmile Branch flows at an average of 18 cfs (ranging from 6.5 cfs to 96 cfs). The relatively level land and a cover growth of Pensacola Bahia grass effectively control surface erosion at the SWMF. Surface drainage ditches channels are cut to control the runoff of rainwater to provide further erosion control (Ref. 73).

H, S, and Z Areas

A topographic map showing surface drainage near H Area is shown in Figure 1.3-18. The CIF is at an elevation of approximately 300 feet above msl. The nearest significant stream is Upper Three Runs Creek, located about 1.6 miles north of the CIF. Upper Three Runs Creek flows at elevations less than 150 feet above msl. The mean annual flow at a gauging station approximately 3 miles from H Area is 215 cfs. The measured maximum flow for 1974 to 1986 was about 950 cfs. Runoff from precipitation is carried away from structures by natural contours or catch basins that divert water into the Upper Three Runs Creek watershed. Upper Three Runs Creek empties into the Savannah River. Upper Three Runs Creek is not used as a drinking water supply for any population group.

S and Z Areas are located on a local topographic high (minimum grade level 275 feet msl). S Area is within the Savannah River drainage basin at the divide between Crouch Branch and McQueen Branch watersheds. Z Area is located north of S Area. Runoff from Z Area is diverted indirectly to McQueen Branch. McQueen Branch drains into Tinker Creek near its junction with Upper Three Runs Creek, and Crouch Branch drains directly into Upper Three Runs Creek. All streams in the area are at substantially lower elevations than S and Z Areas.

USGS gauging stations for McQueen Branch and Crouch Branch are in place. Stage data are being collected to develop ratings for these newly installed stations.

HYDROSPHERE - SAVANNAH RIVER SITE AREAS

The location, size, shape, and other hydrological characteristics of streams, rivers, lakes, shore regions, and groundwater environments that influence the general site are described below.

F and E Areas

F Area is on a near-surface groundwater divide between Upper Three Runs Creek and an unnamed tributary of Fourmile Branch. The near-surface groundwater from the southern part of F Area discharges to an unnamed tributary of Fourmile Branch, approximately 2,000 feet to the south. The near-surface groundwater from the northern part of F Area discharges to one of many tributaries of Upper Three Runs Creek, approximately 1,500 feet to the north.

The nearest site boundary from the E-Area SWMF is approximately 6 miles (9.6 km) to the west. The site is located on a water-table divide. From the original Solid Waste Storage Facility (Old Burial Ground, 643-E), surface flow is southwest towards a small tributary of Fourmile Branch. Groundwater from the northeastern parts of the Solid Waste Disposal Facility (SWDF) (643-7E) and the Mixed Waste Management Facility (MWMF) (643-28E) flows toward the north-northwest. Groundwater from the southwestern portions of SWMF 643-7E and the MWMF flows toward the west-southwest. Groundwater under the northwestern parts of SWMF 643-7E and the MWMF flows toward the west, and groundwater under the eastern portions of SWMF 643-7E and the MWMF flows toward the east-southeast.

H, S, and Z Areas

H Area is located near a water-table divide between Upper Three Runs Creek and Fourmile Branch. Near-surface groundwater from the southern part of H Area discharges to an unnamed tributary of Fourmile Branch, approximately 1,000 feet south of H Area. Near-surface groundwater from the northern part of H Area discharges to one of two tributaries of Upper Three Runs Creek, which are approximately 1,500 and 4,000 feet north of H Area, respectively.

The nearest site boundary to S Area is approximately 6.5 miles (10.5 km) to the north. Near-surface groundwater flows toward McQueen Branch, approximately 0.75 mile (1.2 km) to the northeast.

HYDROSPHERE – SURFACE WATERS

Savannah River

SRS is bounded on the southwest for approximately 17 miles (27 km) by the Savannah River. The Savannah River Basin (see Figure 1.4-14) is one of the major river basins in the southeastern U.S. It has a drainage area of 10,577 square miles, of which 8,160 square miles are upstream of SRS. The headwaters of the Savannah River are in the Blue Ridge Mountains of North Carolina, South Carolina, and Georgia. The river forms at the junction of the Tugaloo and Seneca Rivers approximately 100 miles northwest of SRS, now the site of Hartwell Reservoir, and empties into the Atlantic Ocean near Savannah, GA, approximately 95 miles southeast of SRS. From the Hartwell Reservoir Dam to the Savannah Harbor, the river runs a course of 289 river miles.

Three large reservoirs on the Savannah River upstream of SRS provide hydroelectric power, flood control, and recreation. Strom Thurmond Reservoir (2.51 million acre-feet), completed in 1952 (Table 1.3-16), is approximately 35 miles (65 river km) upstream of SRS. The Richard B. Russell Reservoir (1.026 million acre-feet), completed in 1984, is approximately 72 miles (103 river km) upstream of SRS. Hartwell Reservoir (2.549 million acre-feet), completed in 1961, is approximately 90 miles (133 river km) upstream of SRS (see Figure 1.4-15). These three dams are owned by the U.S. Army Corps of Engineers. The Stevens Creek Dam, also on the Savannah River, is owned by SCE&G.

Additional dams lie upstream of Hartwell Reservoir and are used primarily for hydroelectric power generation (see Figure 1.4-15). The Yonah, Tugaloo, Tallulah Falls, Mathis, Nacoochee, and Burton Dams are owned by Georgia Power Company, and the Keowee, Little River, and Jocassee Dams are owned by Duke Power Company. Although many of these dams impound water to depths in excess of 100 feet, only Jocassee Dam and the combined Little River-Keowee Dams impound significant quantities (approximately 1 million acre-feet each).

Dredging operations on the Savannah River have been conducted by the U.S. Army Corps of Engineers since 1958. This program was designed to dredge and maintain a 9-foot navigation channel in the Savannah River from Savannah to Augusta, Georgia. Dredging of the Savannah River was discontinued in 1979. Sixty-one sets of pile dikes were placed to constrict the river flow, increasing flow rates, and 38,000 feet of a wood and stone revetment were laid to reduce erosion on banks opposite the dikes. In addition, the channel was dredged and 31 cutoffs were made, reducing the total river distance from Augusta to Savannah by approximately 15 miles. The project was completed in July 1965; periodic dredging has been performed to maintain the channel (Ref. 45, 46).

The Savannah River is gauged above SRS near Augusta, GA (station 02197000), 0.5 mile downstream from Upper Three Runs Creek at Ellenton Landing (station 02197320), at Steel Creek (station 02197357), and below SRS at Burtons Ferry Bridge (station 02197500) and 3 miles north of Clyo, GA (station 02198500) (see Figure 1.4-14) (Ref. 74). Since upstream stabilization, the yearly average flow of the Savannah River near SRS has been approximately 10,419 cfs (Ref. 75). Flow extremes are discussed in Section 1.5.1. The elevation of the river at SRS pumphouses is 80.4 feet msl at a flow of 5,800 cfs. The Savannah River has a flow of 5,800 cfs and has an average velocity of approximately 2 mph at VEGP, which is across the river from SRS (see Figure 1.4-14) (Ref. 76). The river is about 340 feet wide and from 9 to 16 feet deep. The minimum flow that is required for navigation downstream from Strom Thurmond Dam is 5,800 cfs. From SRS, river water usually reaches the coast in approximately 5 to 6 days, but may take as few as 3 days (Ref. 74).

Three locations below the mouth of Upper Three Runs Creek pump raw water from the Savannah River for drinking water supplies. The Cherokee Hill Water Plant at Port Wentworth, GA (see Figure 1.4-14) can withdraw about 70 cfs for an effective consumer population of about 20,000. The Beaufort-Jasper Water Treatment Plant at Hardeeville, SC (see Figure 1.4-14) can withdraw about 12 cfs for a consumer population of approximately 51,000. The SRS D Area, downstream of the mouth of Upper Three Runs Creek, removes approximately 0.1 cfs from the river.

Savannah River water is also used for industrial water cooling purposes by several facilities. SRS is a major user, with intake points downstream of the confluence of Upper Three Runs Creek with the Savannah River. SRS could remove 1,450 cfs with all pumps in three pumphouses concurrently in use, but usually withdraws a maximum of 1,320 cfs from the river. C, K, and L Reactors could each receive about 400 cfs of cooling water when active. The coal-fired power plant in D Area receives about 100 cfs, and Par Pond receives about 20 cfs to compensate for seepage and evaporation. VEGP uses 100 cfs and SCE&G's Urquhart Steam Station, located between Augusta and SRS (see Figure 1.4-14), uses 260 cfs.

Upper Three Runs Creek

Upper Three Runs Creek is the longest of the plant streams. It drains an area of over 195 square miles and differs from the other five onsite streams in two respects. It is the only stream with headwaters arising outside the site. It is the only stream that has never received heated discharges of cooling water from the production reactors. Tims Branch receives primarily treated industrial wastewaters from M Area, SRTC, a small coal-fired plant, and treated sanitary wastewater and remediated groundwater from A and M Areas.

The minimum and maximum flow history for Upper Three Runs Creek is discussed in Section 1.5.1.2. The Upper Three Runs Creek stream channel has a low gradient and is meandering, especially in the lower reaches. Its floodplain ranges in width from 0.25 to 1 mile and contains extensive stands (about 98% coverage) of bottomland hardwood forest (Ref. 77). Within SRS, the Upper Three Runs Creek valley is asymmetrical, having a steep southeastern side and a gently sloping northwestern side.

Upper Three Runs Creek is gauged near Highway 278 (station 02197300 relocated downstream), at SRS Road C (station 02197310), and at SRS Road A about 3 miles above the confluence of Upper Three Runs Creek with the Savannah River (station 02197315) (see Figure 1.4-12). The Highway 278 station is a National Hydrologic Benchmark Station. Benchmark streams are measured monthly for water flow, temperature, and quality to provide hydrologic data on river basins governed by natural conditions.

The average Upper Three Runs Creek flow at Highway 278 from 1966 to 1986 was 106 cfs, which represents a water yield of about 1.0 cubic feet per square mile or 16.55 inches/year from the drainage basin (Ref. 77). The average annual precipitation at SRS is 48.3 inches (Ref. 78). Thus, in the upper reaches of Upper Three Runs Creek, about 35% of the rainfall appears as stream discharge. Flow rates are also measured downstream of the Route 278 site at SRS Road C and at SRS Road A. Average daily flows were calculated to be 102, 203, and 251 cfs, respectively. The minimum daily flow rates recorded at these sites during this period were 45, 117, and 124 cfs, respectively.

Fourmile Branch

Fourmile Branch drains about 23 square miles within SRS, including much of the F, H, and C Areas (see Figure 1.4-12). The creek flows to the southwest into the Savannah River Swamp and then into the Savannah River. The valley is V-shaped, with the sides varying from steep to gently sloping. The floodplain is up to 1,000 feet wide. There is no human population resident in the Fourmile Branch drainage.

Fourmile Branch receives effluents from F, H, and C Areas; and a groundwater plume from the burial ground, F Seepage Basin, and H Seepage Basin (use discontinued in November 1988). Until June 1985, it received large volumes of cooling water from the production reactor in C Area. The creek valley has been modified by the cooling water discharge, which has created a delta into the Savannah River Swamp. Fourmile Branch also receives tritium and strontium-90 migrating from the F- and H-Area seepage basins and the SWMF.

Water flow measurements have been made on Fourmile Branch near Road A-12.2 at SRS (station 02197344) since November 1976. Mean monthly flows for water years 1986 and 1987, after C Reactor shutdown, ranged from 88 cfs in January 1986 to 17 cfs in August 1987 (Ref. 74, 79). Extreme flows for this period were 436 cfs (gage height 3.14 feet) on March 1, 1987, to 13 cfs on August 24-25 and 28-29, 1987. The maximum and minimum discharges for the period of record are 903 cfs (gage height 3.93 feet) on March 13, 1980, and 13 cfs on August 24-25 and 28-29, 1987, respectively (Ref. 74).

ENVIRONMENTAL ACCEPTANCE OF EFFLUENTS

All NPDES permitted outfalls within the SRS are identified in the annual Savannah River Site Environmental Report (Ref. 20).

CHEMICAL AND BIOLOGICAL COMPOSITION OF ADJACENT WATERCOURSES

Upper Three Runs Creek

The Upper Three Runs Creek valley is swampy with a meandering and braided channel, especially in the lower reaches. In the SRS, the stream has a gradient of approximately 5.3 ft/mile (1 m/km). A study of Upper Three Runs Creek stream channel sediments (Ref. 94) found sand to be the dominant fraction, with silt plus clay fractions increasing to about 40% at Road A.

Upper Three Runs Creek is a slightly dystrophic, large, cool, blackwater stream. The stream is neutral to somewhat acidic and carries a relatively low load of suspended and dissolved organics compared to other streams of the southeastern Atlantic Coastal Plain (Ref. 94). Suspended solid loads are heaviest during periods of highest stream flow, normally late winter to early spring when vegetative cover is reduced. From the upper to lower reaches, the suspended load increases substantially. Although inorganic sediments are preferentially deposited in the floodplains, there is a concurrent input of organics from the floodplains, which causes an increase in total suspended solids (mostly organic matter). This increase is more pronounced in periods when the stream overflows its banks and floods the surrounding swamps. Water quality samples for Upper Three Runs Creek are collected monthly and the data are presented in the annual SRS Environmental Report (Ref. 20).

The water of Upper Three Runs Creek is soft, usually clear, and low in nutrients. The temperature ranges from approximately 5 to 26°C, with lows occurring from December through February. The highest temperature and lowest flow are normally observed in July. Temperature, pH, and dissolved oxygen levels in the stream meet South Carolina Water Classification Standards for Class B streams (Ref. 94). Conductivity, suspended solids, and alkalinity concentrations increase in the downstream direction, but the concentrations are low at all stations. Nutrient levels are also low, although phosphorus and nitrate levels are highest during the spring and summer, possibly due to offsite agricultural activities.

The effluents include process wastes, cooling water, surface runoff, and ash basin effluent. The F/H ETF discharges into Upper Three Runs Creek near Road C. Tims Branch (see Figure 1.4-12), a tributary to Upper Three Runs Creek, has received trace amounts of radioactivity and heavy metals contamination and is currently receiving elevated levels of nitrates from M Area (Ref. 93). Total discharges to Upper Three Runs Creek range from approximately 10 gpm to over 1,000 gpm. By comparison, the minimum recorded flow at the Highway 278 gage about 10 miles upstream on Upper Three Runs Creek is 66 cfs, which is approximately 30,000 gpm (Ref. 92).

The cation exchange capacity (CEC) ranged from 0.1 to 12.4 milliequivalent per 100 grams (meq/100 g) in all Upper Three Runs Creek and tributary sediments, indicating low CEC values throughout the Upper Three Runs Creek watershed. Elevated levels of nickel were found in Tims Branch sediments, probably originating from the nickel plating operations in M Area (Ref. 94). Sediments from the Upper Three Runs Creek watershed exhibited background levels of Cs-137 ($\leq$ 2 pCi/g) and naturally occurring radionuclides (K-40, radium, Tl-208, and natural uranium) (Ref. 95).

The swamp forest of the Upper Three Runs Creek floodplain consists primarily of bald cypress (Taxodium distichum) and tupelo gum (Nyssa aquatica), while the bottomland hardwoods associated with the stream are mostly sweet gum (Liquidambar styraciflua), red oak (Quercus rubra), and beech (Fagus grandifolia). The stream is well shaded in most reaches.

Leaf litter input is high, and the leaves are rapidly broken down by macroinvertebrate shredders. The relatively complete canopy results in low periphyton and macrophyte biomass, especially in summer when the creek is most shaded. The periphytons that do occur are largely green algae and diatoms (Ref. 90).

Sampling conducted in 1984 and 1985 found ichthyoplankton densities to be low, with spotted suckers the dominant taxon. Crappie and darters also composed a large portion of the overall ichthyoplankton population. The dominant fish species found were redbreast sunfish, spotted suckers, channel catfish, and flat bullhead. Species numbers tend to peak in the spring and drop in the summer (Ref. 93).

Fourmile Branch

Fourmile Branch originates on SRS and flows southwest across the plant toward the Savannah River. In the Savannah River Swamp, when C Reactor operated, part of Fourmile Branch flowed to Beaver Dam Creek, which flows directly into the Savannah River through a breach in the natural levees. With C Reactor in cold standby, Fourmile Branch flows parallel to the river behind the natural levees and enters the river through a breach downriver from the Beaver Dam Creek.

Fourmile Branch receives nonradioactive effluents from C, F, and H Areas, which increase the hardness, nutrient content, and trace metal concentrations in the water. From March 1955 to June 1985, Fourmile Branch also received 180,000 gpm of cooling water from the production reactor in C Area. During this period, water quality in the thermal reaches of the creek generally reflected the waters of the Savannah River, which served as source water for C Reactor (Ref. 96).

During reactor operations, stream temperatures near the mouth of Fourmile Branch (station 02197328) ranged from less than 10°C during the winter to more than 40°C during the summer (Ref. 92), with the highest temperature recorded at 46.8°C on August 22, 1983 (Ref. 88). Mean temperatures for June, July, and August often were greater than 38°C. Temperatures in excess of 60°C were recorded upstream near the C-Area discharge site (Ref. 96). Temperature extremes since reactor shutdown have been 1.5° and 34°C, with mean temperatures for summer months ranging from about 22 to 29°C (see Figure 1.4-16) (Ref. 74, 79).

Fourmile Branch has been greatly influenced by the temperature and volume of cooling water it received from the C-Area production reactor. The native swamp forest has been eliminated and the stream is mostly unshaded. Nutrient removal and reduction of the organic load in the swamp do not occur as effectively as in the past due to the effects of standing hot water from C Area (Ref. 90).

Above its thermal reach, the water quality of Fourmile Branch resembles that of other nonthermal streams on the site (Ref. 94). Samples taken from 1983 to 1985 showed this portion of Fourmile Branch to have higher conductivity, nitrate (as N), calcium, and sodium levels than Upper Three Runs Creek. Levels of copper, cadmium, mercury, nickel, lead, chromium, and zinc were at or near detection limits (Ref. 97). Water temperatures in the nonthermal reaches of Fourmile Branch averaged approximately 17°C, with highs usually less than 30°C.

Water quality samples for Fourmile Branch are collected monthly and the data are presented in the annual SRS Environmental Report (Ref. 20). The mean temperature, the pH range, and the mean dissolved oxygen concentration were similar to those for Upper Three Runs Creek at Road C during the same period. The mean concentrations of most other parameters measured were higher or approximately equal to those for Upper Three Runs Creek. Turbidity, volatile solids, chemical oxygen demand, nitrites, nitrates, and manganese were lower in Fourmile Branch than in the lower reaches of Upper Three Runs Creek (measured at Road C).

When C Reactor was in operation, only the thermophilic blue-green algae (i.e., Phormidium and Oscillatoria spp.) survived regularly in waters exceeding 50°C (Ref. 97, 98). Leaf decomposition was low due to the absence of macroinvertebrate shredders. The macroinvertebrate populations exhibited low biomass and low densities except for some oligochaetes, nematodes, and chironomids that were more heat tolerant. Upstream from this zone, diatoms were the predominant and most diverse primary producers. Blue-green algae of the genera Microcoleus, Schizothrix, and Oscillatoria were found in decaying organic surfaces such as submerged logs and leaf litter. Besides the thermophilic blue-green algae, the mosquito fish was the only other survivor during periods of thermal stress.

Following reactor shutdown in 1985, the macroinvertebrate density and biomass increased. Many fish species have readily reinvaded during this period, and fish catch rates have increased markedly. It is expected that the current biology of Fourmile Branch will more closely resemble that of other site streams.

1.4.2.2 Regional Hydrogeology (Within 75 Mile Radius)

The following subsections are based on and draw directly from information and illustrations contained in Aadland et. al, Hydrogeologic Framework of West-Central South Carolina (1995) (Ref. 100).

REGIONAL HYDROGEOLOGICAL SETTING

Two hydrogeologic provinces are recognized in the subsurface beneath the SRS region (Figure 1.4-18) (Note: Figure 1.4-17 is intentionally omitted.). The uppermost province, which consists of the wedge of unconsolidated Coastal Plain sediments of Late Cretaceous and Tertiary ages, is referred to as the Southeastern Coastal Plain hydrogeologic province. It is further subdivided into aquifer or confining systems, units, and zones. The underlying province, referred to as the Piedmont hydrogeologic province, includes Paleozoic metamorphic and igneous basement rocks and Upper Triassic lithified mudstone, sandstone, and conglomerate in the Dunbarton basin (see Section 1.4.3.1). For reference, a geological time scale is shown in Figure 1.4-19.

The following hydrogeological characteristics are of particular interest from a safety perspective. (The following subsections provide additional details.)

- The layered structure of the coastal plain sediments effectively controls migration of contaminants in the subsurface, limiting vertical migration to deeper aquifers.
- Between the ground surface and the primary drinking water aquifer(s) are several low permeability zones which restrict vertical migration from a given point source.
- The abundance of clay size material and clay minerals in the aquifer and aquitard zones affects groundwater composition and vertical migration. The concentration of some potential contaminants, especially metals and radionuclides, may be attenuated by exchange and fixation of dissolved constituents on clay surfaces.
- The recharge area(s) for the deeper drinking water aquifers used are updip of SRS, near the fall line. Some recharge areas are located at the northern-most fringe of the site.

- Recharge for the water-table aquifers, namely the Upper Three Runs and Gordon Aquifers, is primarily from local precipitation.
- Discharge of groundwater from the Upper Three Runs and Gordon aquifers is typically to the local streams on the SRS.
- Groundwater at the SRS is typically of low ionic, low dissolved solids and moderate pH (typically ranging from 4.4 to 6.0). Other constituents such as dissolved oxygen and alkalinity are more closely associated with recharge and aquifer material. Dissolved oxygen is typically higher in the updip and near-surface recharge areas, and alkalinity, pH and dissolved solids are typically higher in those portions of the aquifers regions containing significant carbonate materials.
- The presence of an upward vertical gradient or "head reversal" between the Upper Three Runs and Gordon aquifers and the Crouch Branch aquifer is significant in that it prevents downward vertical migration of contaminants into deeper aquifers over much of central SRS (Figure 1.4-20).

HYDROSTRATIGRAPHIC CLASSIFICATION AND NOMENCLATURE OF COASTAL PLAIN SEDIMENTS

The method for establishing a nomenclature for the hydrogeologic units in the following discussion is based on Aadland et al. (Ref. 100) and generally follows the guidelines set forth by the South Carolina Hydrostratigraphic Subcommittee.

A hydrogeologic unit is defined by its hydraulic properties (hydraulic conductivity, hydraulic head relationships, porosity, leakance coefficients, vertical flow velocity and transmissivity) relative to those properties measured in the overlying and underlying units (Ref. 101-103). The properties are measured at a type well or type well cluster location (see Figure 1.4-21). Aquifer and confining units are mapped on the basis of the hydrogeologic continuity, potentiometric conditions, and leakance-coefficient estimates for the units. These properties are largely dependent on the thickness, areal distribution, and continuity of the lithology of the particular unit. However, a hydrogeologic unit may traverse lithologic unit boundaries if there is not a significant change in hydrogeologic properties corresponding to the change in lithology.

Delineation and Classification of Units

The hydrostratigraphic classification is based on aquifer and confining units ranked at four levels (I through IV):

Level I - Hydrogeologic Province

A hydrogeologic province is a major regional rock and/or sediment package that behaves as a single unified hydrologic unit. The names, areal extent and underlying geological context of the regional hydrogeologic provinces used in this report are the same as those defined by Miller and Renken (Ref. 104) as regional hydrologic systems. For example, the "Southeastern Coastal Plain *hydrologic* system" of Miller and Renken reads "Southeastern Coastal Plain *hydrogeologic* province" in this report (Figure 1.4-22).

Level II - Aquifer and Confining Systems

These define the primary or regional units of the hydrogeologic province. The aquifer system may be composed of a single aquifer or two or more coalescing aquifers that transmit ground water on a regional basis. Aquifer systems may be locally divided by confining units that impede ground water movement but do not greatly affect the regional hydraulic continuity of the system (Ref. 105). A confining system may be composed of a single confining unit or two or more confining units that serve as an impediment to regional ground water flow. The regional aquifer/confining systems at SRS are presented in Figures 1.4-18 and 1.4-23).

The SRS is located near the updip limit of the aquifer and confining systems comprising the Coastal Plain sediments in the region. Here, the lateral continuity and thickness of the clay and clayey sand beds that constitute the confining systems decrease, and the beds become increasingly discontinuous. Where the clay beds no longer separate the overlying and underlying aquifers, the updip limit of a confining system is defined. Updip from this line, the overlying and underlying aquifer systems coalesce into a single unified aquifer system. Where aquifer systems have combined, some of the individual aquifer and confining units may persist in the updip-combined system.

Level III - Aquifer and Confining Units

These are the fundamental units of the classification. An aquifer is a mappable (> 1036 km^2 [~400 mi^2]) body of rock or sediments that is sufficiently permeable to conduct ground water and yield significant quantities of water to wells and springs (Ref. 106). A confining unit, on the other hand, is a mappable (> 1036 km^2 ~ 400 mi^2]) body of rock or sediments of significantly lower hydraulic conductivity than an adjacent aquifer, and that serves as an impediment to groundwater flow into or out of an aquifer (Ref. 107). A confining unit's hydraulic conductivity may range from nearly zero to some value distinctly lower than that of the nearby aquifer. The assignment of a unit level and name to a hydrostratigraphic unit does not imply a quantitative ranking of hydraulic continuity, but is intended to distinguish relative differences in hydraulic properties between adjacent units. Where the confining unit that separates one aquifer from another thins and becomes laterally discontinuous and/or is breached by faults and fractures, the overlying and underlying aquifers coalesce and a single unified aquifer may be defined. The aquifer/confining units in the SRS region are presented in Figure 1.4-22).

Level IV - Aquifer and Confining Zones

Aquifer and confining units may be informally subdivided into zones that are characterized by properties significantly different from the rest of the unit, such as hydraulic conductivity, water chemistry, lithology, and/or color. For example, an aquifer may contain a "confining zone" such as the "tan clay" confining zone of the Upper Three Runs aquifer. Conversely, a confining unit may contain an "aquifer zone" such as the "middle sand" aquifer zone of the Crouch Branch confining unit. Miller (Ref. 108) describes the "Fernandina permeable zone" in the Lower Floridan aquifer in coastal areas of Georgia, where the permeability greatly exceeds that of the rest of the aquifer.

In the study area, zonal differentiation is undertaken on a local site-specific scale where useful and necessary distinctions are made in the hydraulic characteristics of specific aquifer or confining units. Thus, the intermittent but persistent clay beds in the Dry Branch Formation, informally referred to as the "tan clay" in previous SRS reports, is designated the tan clay confining zone of the Upper Three Runs aquifer. The "tan clay" confining zone is defined specifically for the Dry Branch clay in the General Separations Area of SRS. Correlative clay beds in other parts of the study area may usefully be designated a confining zone but would be given a separate and distinct name.

SOUTHEASTERN COASTAL PLAIN HYDROGEOLOGIC PROVINCE

The Southeastern Coastal Plain hydrogeologic province underlies 310,798,560 km^2 (120,000 square miles) of the Coastal Plain of South Carolina, Georgia, Alabama, Mississippi, and Florida and a small contiguous area of southeastern North Carolina. This hydrogeologic province grades laterally to the northeast into the Northern Atlantic Coastal Plain Aquifer System (Ref. 109) and to the west into the Mississippi embayment and Coastal Lowlands Aquifer Systems (Ref. 110). In South Carolina, the northern and northwestern limits of the province are its contact with crystalline rocks at the Fall Line, which marks the updip limit of Coastal Plain sediments.

The Southeastern Coastal Plain hydrogeologic province comprises a multilayered hydraulic complex in which retarding beds composed of clay and marl are interspersed with beds of sand and limestone that transmit water more readily. Ground water flow paths and flow velocity for each of these units are governed by the unit's hydraulic properties, the geometry of the particular unit, and the distribution of recharge and discharge areas. Miller and Renken (Ref. 104) divided the Southeastern Coastal Plain hydrogeologic province into seven regional hydrologic units. These are four regional aquifer units separated by three regional confining units. Six of the seven hydrologic units are recognized in the SRS area and are referred to as hydrogeologic systems. These systems have been grouped into three aquifer systems divided by two confining systems, all of which are underlain by the Appleton confining system. The Appleton separates the Southeastern Coastal Plain hydrogeologic province from the underlying Piedmont hydrogeologic province. The regional lithostratigraphy and hydrostratigraphic subdivision of the Southeastern Coastal Plain hydrogeologic province is shown in Figure 1.4-18.

In descending order, the aquifer systems beneath SRS are the Floridan Aquifer System, the Dublin Aquifer System, and the Midville Aquifer System (see Figure 1.4-18). In descending order, the confining systems are the Meyers Branch confining system, the Allendale confining system, and the Appleton confining system.

Beneath the SRS, the Midville and Dublin Aquifer Systems each consists of a single aquifer, the McQueen Branch aquifer and Crouch Branch aquifer, respectively. Downdip, beyond the SRS, these aquifer systems are subdivided into several aquifers and confining units.

The Floridan Aquifer System consists of two aquifers in the study area, the Upper Three Runs aquifer unit, and the underlying Gordon aquifer unit, which are separated by the Gordon confining unit. Northward, the Gordon and Upper Three Runs aquifer units coalesce to form the Steed Pond aquifer.

The Allendale and Meyers Branch confining systems each consists of a single confining unit in the study area, the McQueen Branch and Crouch Branch confining units, respectively. The basal Appleton confining system is thought to consist of a single confining unit in the study area. The confining unit, "Appleton" however, has not been formally defined owing to insufficient data. Downdip, each confining system may be subdivided into several confining units and aquifer units.

Where the confining beds of the Allendale confining system no longer regionally separate the Dublin and Midville Aquifer Systems hydrologically, the Dublin-Midville Aquifer System is defined (see Figures 1.4-18 and 1.4-23). Similarly, where the Meyers Branch confining system no longer regionally separates the Floridan Aquifer System from the underlying Dublin-Midville Aquifer System, the entire sedimentary sequence from the top of the Appleton confining system to the water-table is hydraulically connected and the Floridan-Midville Aquifer System is defined.

In general, the number of aquifer systems present beneath the SRS decreases updip (see Figure 1.4-22). This is due to pinch out of confining units in the updip direction. Thus, in the southern site area, three aquifer systems are designated. As the confining systems become ineffective flow barriers updip, the number of aquifer systems decreases to one (Floridan-Midville) in the northern site region. As indicated in Figure 1.4-22, the nomenclature and stratigraphic position of the two aquifer system areas is dependent on which confining system (Allendale or Meyers Branch) pinches out.

The following discussion treats each of the hydrogeologic units in greater detail. It presents the units in descending order, from water-table to the Piedmont hydrogeologic province. Within each unit, the discussion traces the unit updip. In general, confining layers pinch out and aquifers coalesce in an updip direction.

<u>Floridan Aquifer System</u>

Miller (Ref. 106) defined the Floridan Aquifer System as a "vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of middle and late Tertiary age and hydraulically connected in varying degrees and whose permeability is, in general, an order to several orders of magnitude greater than that of those rocks that bound the system above and below". Thus, the definition of the Floridan Aquifer System is partly lithologic and partly hydraulic. The system is sometimes referred to as the principal artesian aquifer in South Carolina, Georgia, and Alabama (Ref. 106, 110). The rocks that characterize the main body of the Floridan are mostly platform carbonates.

The Floridan Aquifer System includes the platform carbonates as noted by Miller (Ref. 106) as well as the updip equivalent clastics that are in hydrogeologic communication with the carbonates. The updip clastic facies equivalents of the Floridan carbonate rocks are not considered by Miller (Ref. 106) to be part of the Floridan Aquifer System. However they are hydraulically connected with it and are part of its regional flow system. Thus, the updip clastic facies equivalent of the Floridan Aquifer System and the carbonate phase of the Floridan Aquifer System are treated as a single hydrologic unit (the Florida Aquifer System) (Ref. 100). The updip clastic facies equivalents represent the recharge areas for the downdip Floridan. The downdip carbonate phase of the Floridan Aquifer System is used extensively in the southeastern part of the South Carolina Coastal Plain as an aquifer.

The transition zone between the carbonate rocks of the Floridan and the updip clastic facies equivalents of the system is the approximate northern extent of the thick carbonate platform that extended from the Florida peninsula through the coastal area of Georgia to southwestern South Carolina during early Tertiary time. The transition zone extended toward the north to a line approximated by the updip limit of the Santee Limestone platform carbonate beds (Ref. 111). At SRS, which lies mostly north of the line established for the updip limit of the carbonate phase of the Floridan Aquifer System, there are thin beds and lenses of limestone that may be either connected to the main limestone body or isolated from it, owing in part to depositional isolation or to postdepositional erosion or diagenetic alteration. They are considered part of the updip clastic phase of the Floridan.

Carbonate Phase of the Floridan Aquifer System

The carbonate phase of the Floridan Aquifer System that develops in the southernmost fringe of the SRS, just south of well C-10 (see Figure 1.4-22), is divided into the Upper and the Lower Floridan aquifer units (Ref. 111), separated by the "middle confining unit". The hydraulic characteristics of the carbonate phase of the Floridan Aquifer System vary considerably in the South Carolina-Georgia region. This results from several different processes, the most important being the dissolution of calcium carbonate by groundwater. The variability in the amount of dissolution is strongly influenced by the chemical composition of the water and the local differences in geology and lithology that affect the rate of groundwater movement.

Hydraulic parameters data for the Floridan Aquifer System are given in Table 1.4-18.

Clastic Phase of the Floridan Aquifer System

The updip clastic phase of the Floridan Aquifer System dominates in the SRS region and consists of a thick sequence of Paleocene to late Eocene sand with minor amounts of gravel and clay and a few limestone beds. At the southern fringe of the SRS, the clastic sediments of the aquifer system grade directly into the platform limestone that forms the carbonate phase of the Floridan. The lithologic transition between the clastic phase and the carbonate phase of the aquifer system does not represent a hydrologic boundary, and the two lithofacies are in direct hydrogeologic communication. The Floridan Aquifer System overlies the Meyers Branch confining system throughout the lower two-thirds of the study area. Toward the north, the confining beds of the Meyers Branch confining system thin, become intermittent, and the entire Floridan Aquifer System coalesces with the Dublin-Midville Aquifer System to form the Floridan-Midville Aquifer System (see Figures 1.4-18 and 1.4-23).

In the central portion of SRS, clay to sandy clay beds in the Warley Hill Formation (Figure 1.4-18) support a substantial head difference between overlying and underlying units. These fine-grained sediments constitute the Gordon confining unit, which divides the system into two aquifers: the Gordon aquifer unit and the overlying Upper Three Runs aquifer unit. The former of the two is between the lower surface of the Gordon confining unit and the upper surface of the Crouch Branch confining unit. Updip, the Warley Hill sediments do not support a substantial head difference; thus, there is only one aquifer unit (the Steed Pond aquifer).

The sedimentary sequence that corresponds to the updip clastic phase of the Floridan Aquifer System is penetrated in the P-27 reference well (see Figure 1.4-22) near the center of SRS. The system at P-27 is 65.8 meters (216 feet) thick; the base is at 14.6 meters (48 feet) msl, and the top occurs at the water-table, which is at 80.5 meters (264 feet) msl, or 3.1 meters (10 feet) below land surface. The system includes 6.7 meters (22 feet) of clay in five beds, and the remainder consists of sand and clayey sand beds. The stratigraphic units that constitute the clastic phase of the Floridan Aquifer System include the Fourmile Formation and the locally sandy parts of the Snapp Formation of the Black Mingo Group, all of the Orangeburg and Barnwell Groups, and the overlying Miocene/Oligocene "Upland unit" (see Figure 1.4-18).

Recharge of the Floridan occurs generally in the northwestern part of the study area, where rainfall percolates into the outcrop of the Gordon and Upper Three Runs aquifers. The Savannah River has the greatest area-wide influence on water levels, followed by the South Fork Edisto River and, to a much lesser degree, the Salkahatchie River. In the updip portion of the study area, Upper Three Runs Creek controls the direction of groundwater movement. Here, the Gordon confining unit has been breached by the stream, creating a groundwater sink that induces flow out of the Gordon toward the stream. Using an average transmissivity value of 28 m^2/day (300 ft^2/day) and an average hydraulic gradient of 4.7 m/km (25 ft/mi) near Upper Three Runs Creek, an estimated 423,920 L/day (112,000 gal/day) is being discharged through each 1-mile strip of the aquifer along the creek, for a total of 5.3 million L/day (1.4 million gal/day).

The transmissivity of the clastic and carbonate phases of the Floridan is lowest near their updip limits because of the reduced aquifer thickness there. Krause (Ref. 112) observed that the transmissivity increases rapidly from the northwest to the southeast along the Savannah River through the clastic facies and across the limestone facies change of the Floridan Aquifer System.

Upper Three Runs Aquifer Unit

The Upper Three Runs Aquifer Unit occurs between the water-table and the Gordon Confining Unit and includes all strata above the Warley Hill Formation (in updip areas) and the Blue Bluff Member of the Santee Limestone (in downdip areas, Figure 1.4-18). It includes the sandy and sometimes calcareous sediments of the Tinker/Santee Formation and all the heterogeneous sediments in the overlying Barnwell Group. The Upper Three Runs aquifer is the updip clastic facies equivalent of the Upper Floridan aquifer in the carbonate phase of the Floridan Aquifer System (see Figure 1.4-22).

The Upper Three Runs aquifer is defined by the hydrogeologic properties of the sediments penetrated in well P-27 (see Figure 1.4-21) located near Upper Three Runs Creek in the center of

SRS. Here, the aquifer is 40 meters (132 feet) thick and consists mainly of quartz sand and clayey sand of the Tinker/Santee Formation; sand with interbedded tan to gray clay of the Dry Branch Formation; and sand, pebbly sand, and minor clay beds of the Tobacco Road Formation. Calcareous sand, clay, and limestone, although not observed in the P-27 well, are present in the Tinker/Santee Formation throughout the General Separations Area near well P-27.

Downdip, at the C-10 reference well, the Upper Three Runs aquifer is 116 meters (380 feet) thick and consists of clayey sand and sand of the upper Cooper Group; sandy, shelly limestone, and calcareous sand of the lower Cooper Group/Barnwell Group; and sandy, shelly, limestone and micritic limestone of the Santee Limestone (see Figure 1.4-21).

Water-level data are sparse for the Upper Three Runs aquifer unit except within SRS. The hydraulic-head distribution of the aquifer is controlled by the location and depth of incisement of creeks that dissect the area. The incisement of these streams and their tributaries has divided the interstream areas of the water-table aquifer into "groundwater islands." Each "groundwater island" behaves as an independent hydrogeologic subset of the water-table aquifer with unique recharge and discharge areas. The stream acts as the groundwater discharge boundary for the interstream area. The head distribution pattern in these groundwater islands tends to follow topography and is characterized by higher heads in the interstream area with gradually declining heads toward the bounding streams (see Figure 1.4-24). Groundwater divides are present near the center of the interstream areas. Water-table elevations reach a maximum of 76 meters (250 feet) msl in the northwest corner of the study area and decline to approximately 30 meters (100 feet) msl near the Savannah River.

Porosity and permeability of the Upper Three Runs aquifer are variable across the study area. In the northern and central regions, the aquifer yields only small quantities of water, owing to the presence of interstitial silt and clay and poorly sorted sediments that combine to significantly reduce permeability. Local lenses of relatively clean, permeable sand however, may, yield sufficient quantities for domestic use. Such high-permeability zones have been observed in the General Separations Area near the center of the study area and may locally influence the movement of groundwater (Ref. 113).

Porosity and permeability were determined for Upper Three Runs aquifer sand samples containing less than 25 percent mud, using the Beard and Weyl method (Ref. 114). Porosity averages 35.3 percent; the distribution is approximately normal, but skewed slightly toward higher values. Geometric mean permeability is 31.5 Darcies (23 m/day [76.7 ft/day]) with about 60 percent of the values between 16 and 64 Darcies (12 and 48 m/day [39 and 156 ft/day]).

Pumping-test and slug-test results in the General Separations Area indicate that hydraulic conductivity is variable, ranging from less than 0.3 (1.0 ft/day) to 10 m/day (32.8 ft/day). Hydraulic conductivity values derived from long-duration, multiple-well aquifer tests are in the range of 3 m/day (10 ft/day), which may be a more reliable estimation of average hydraulic conductivity. At the south end of the study area, near well C-10, sediments in the aquifer become increasingly calcareous, the amount of silt and clay tends to decline, and permeability and yields generally increase. Here, hydraulic-conductivity values are in the 18 m/day (59 ft/day) range.

The majority of hydrogeologic data available on the Upper Three Runs aquifer is from wells in the General Separations Area at SRS. Thus, the discussion that follows is largely focused on that area. The Upper Three Runs aquifer is divided into two aquifer zones divided by the tan clay confining zone. In the General Separations Area, the "upper" aquifer zone consists of all saturated strata in the upper parts of the Dry Branch Formation and the Tobacco Road Formation that lie between the water-table and the "tan clay" confining zone. The aquifer zone has a general downward hydraulic potential into the underlying aquifer unit. The confining beds of the "tan clay" located near the base of the Dry Branch Formation impede the vertical movement of water and often support a local hydraulic head difference. The "lower aquifer" zone of the Upper Three Runs aquifer occurs between the "tan clay" confining zone and the Gordon confining unit and consists of sand, clayey sand and calcareous sand of the Tinker/Santee Formation and sand and clayey sand of the lower part of the Dry Branch Formation.

Slug tests, minipermeameter tests, pumping tests, and sieve analyses have been used to calculate hydraulic-conductivity values for the "upper" aquifer zone near the General Separations Area. Hydraulic-conductivity values derived from 103 slug tests range from a high of 14 m/day (45.4 ft/day) to a low of 0.02 m/day (0.07 ft/day) and average (arithmetic mean) 1.5 m/day (5.1 ft/day) (Ref. 115).

As stated previously, the "tan clay" confining zone at the General Separations Area separates the "upper" aquifer zone from the "lower" aquifer zone in the Upper Three Runs aquifer. This zone is a leaky confining zone. Total thickness of the "tan clay" confining zone, based on measurements at 46 wells distributed throughout the General Separations Area, ranges from 0 to 10 meters (32.8 feet) and averages 3.4 meters (11 feet). The sandy clay to clay beds range from 0 to 5.5 meters (18 feet) in thickness and average 2.1 meters (7 feet). The clayey sand beds range from 0 to 3.7 meters (12 feet) and average 1 meter (3 feet).

Laboratory analyses, including horizontal and vertical hydraulic conductivity, were run on 28 selected clayey sand samples and 55 sandy, often silty clay, and clay samples from the various confining units and "low-permeability" beds in the aquifers (Ref. 103). The results are presented in Table 1.4-19. The generally accepted value of effective porosity used in the study to determine vertical-flow velocities is 5% for the clay to sandy clay beds (Ref. 116) and 12% for the clayey sand beds (Ref. 117).

Recharge to the Upper Three Runs aquifer occurs at the water-table by infiltration downward from the land surface. In the "upper" aquifer zone, part of this groundwater moves laterally toward the bounding streams while part moves vertically downward. The generally low vertical hydraulic conductivities of the "upper" aquifer zone and the intermittent occurrence of the "tan clay" confining zone retard the downward flow of water, producing vertical hydraulic-head gradients in the "upper" aquifer zone and across the "tan clay" confining zone.

Downward hydraulic-head differences in the "upper" aquifer zone vary from 1.4 to 1.64 meters (4.5 to 5.4 feet), and differences across the "tan clay" are as much as 6.5 meters (15.8 feet) in H Area. At other locations in the General Separations Area, the head difference across the "tan clay" confining zone is only 0.3 to 1 meter (0.1 to 3.2 feet), essentially what might be expected due simply to low vertical flow in a clayey sand aquifer. Therefore, the ability of the "tan clay" confining zone to impede water flow varies greatly over the General Separations Area.

Groundwater leaking downward across the "tan clay" confining zone recharges the "lower" aquifer zone of the Upper Three Runs aquifer. Most of this water moves laterally toward the bounding streams; the remainder flows vertically downward across the Gordon confining unit into the Gordon aquifer. All groundwater moving toward Upper Three Runs Creek leaks through the Gordon confining unit or enters small streams. Vertical hydraulic-head differences in the "lower" aquifer zone range from 0.5 to 1 meter (1.5 to 3.2 feet) in H Area and indicate some vertical resistance to flow.

Gordon Confining Unit

Clayey sand and clay of the Warley Hill Formation and clayey, micritic limestone of the Blue Bluff Member of the Santee Limestone constitute the Gordon confining unit. The Gordon confining unit separates the Gordon aquifer from the overlying Upper Three Runs aquifer. The unit has been informally termed the "green clay" in previous SRS reports.

In the study area, the thickness of the Gordon confining unit ranges from about 1.5 to 26 meters (5 to 85 feet). The unit thickens to the southeast. From Upper Three Runs Creek to the vicinity of L Lake and Par Pond, the confining unit generally consists of one or more thin clay beds, sandy mud beds, and sandy clay beds intercalated with subordinate layers and lenses of quartz sand, gravelly sand, gravelly muddy sand, and calcareous mud. Southward from L Lake and Par Pond, however, the unit undergoes a stratigraphic facies change to clayey micritic limestone and limey clay typical of the Blue Bluff Member. The fine-grained carbonates and carbonate-rich muds constitute the farthest updip extent of the "middle confining unit" of the Floridan Aquifer System (the hydrostratigraphic equivalent of the Gordon confining unit), which dominates in coastal areas of South Carolina and Georgia.

North of the updip limit of the Gordon confining unit, the fine-grained clastics of the Warley Hill Formation are thin, intermittent, and no longer effective in regionally separating groundwater flow. Here, the Steed Pond aquifer is defined. Although thin and intermittent, the clay, sandy clay, and clayey sand beds of the Warley Hill Formation can be significant at the site-specific level and often divide the Steed Pond aquifer into aquifer zones.

The values for hydraulic conductivity obtained from the Gordon confining unit are comparable to the average vertical hydraulic-conductivity values of clayey sand 2.71×10^{-3} m/day (8.9×10^{-3} ft/day) and sandy clay to clay 5.09×10^{-5} m/day (1.7×10^{-4} ft/day) calculated for 83 samples analyzed in the Tertiary/Cretaceous section. Selected parameters determined for the unit are listed in Table 1.4-20.

Gordon Aquifer Unit

The Gordon aquifer consists of all the saturated strata that occur between the Gordon confining unit and the Crouch Branch confining unit in both the Floridan - Midville Aquifer System and the Meyers Branch confining system. The aquifer is semiconfined, with a downward potential from the overlying Upper Three Runs aquifer observed in interfluvial areas, and an upward potential observed along the tributaries of the Savannah River where the Upper Three Runs aquifer is incised. The thickness of the Gordon aquifer ranges from 12 meters (38 feet) at well P-4A to 56 meters (185 feet) at well C-6 (see Figure 1.4-21) and generally thickens to the east and southeast. Thickness variations in the confining lithologies near the Pen Branch Fault suggest depositional effects owing to movements on the fault in early Eocene time. The Gordon aquifer is partially eroded near the Savannah River and Upper Three Runs Creek. The regional potentiometric map of the Gordon aquifer (see Figure 1.4-25) indicates that major deviations in the flow direction are present where the aquifer is deeply incised by streams that drain water from the aquifers.

The Gordon aquifer is characterized by the hydraulic properties of the sediments penetrated in reference well P-27 located near the center of SRS. The unit is 23 meters (75.5 feet) thick in well P-27 and occurs from 38 to 15 meters (125 to 48 feet) msl. The aquifer consists of the sandy parts of the Snapp Formation and the overlying Fourmile and Congaree Formations (see Figure 1.4-18). Clay beds and stringers are present in the aquifer, but they are too thin and discontinuous to be more than local confining beds. The aquifer in wells P-21 and P-22 (see Figure 1.4-25) includes a clay bed that separates the Congaree and Fourmile Formations. The clay bed appears sufficiently thick and continuous to justify splitting the Gordon aquifer into zones in the southeastern quadrant of SRS.

Downdip, the quartz sand of the Gordon aquifer grades into quartz-rich, fossiliferous lime grainstone, packstone, and wackestone, which contain considerably more glauconite than the updip equivalents. Porosity of the limestone as measured in thin-section ranges from 5 to 30 percent and is mostly moldic and vuggy.

South of SRS, near well ALL-324 (see Figure 1.4-21), the Gordon aquifer consists of interbedded glauconitic sand and shale, grading to sandy limestone. Farther south, beyond well C-10, the aquifer grades into platform limestone of the Lower Floridan aquifer of the carbonate phase of the Floridan Aquifer System.

The Gordon aquifer is recharged directly by precipitation in the outcrop area and in interstream drainage divides in and near the outcrop area. South of the outcrop area, the Gordon is recharged by leakage from overlying and underlying aquifers. Because streams such as the Savannah River and Upper Three Runs Creek cut through the aquifers of the Floridan Aquifer System, they represent no-flow boundaries. As such, water availability or flow patterns on one side of the boundary (stream) will not change appreciably due to water on the other side. In the central part of SRS, where the Gordon confining unit is breached by faulting, recharge to the Gordon aquifer is locally increased (Ref. 100).

Most of the Gordon aquifer is under confined conditions, except along the fringes of Upper Three Runs Creek (i.e., near the updip limit of the Gordon Confining Unit) and the Savannah River. The potentiometric-surface map of the aquifer (see Figure 1.4-25) shows that the natural discharge areas of the Gordon aquifer at SRS are the swamps and marshes along Upper Three Runs Creek and the Savannah River. These streams dissect the Floridan Aquifer System, resulting in unconfined conditions in the stream valleys and probably in semiconfined (leaky) conditions near the valley walls. Reduced head near Upper Three Runs Creek induces upward flow from the Crouch Branch aquifer and develops the "head reversal" that is an important aspect of the SRS hydrogeological system (see Figure 1.4-20). The northeast-southwest oriented hydraulic gradient across SRS is consistent and averages 0.9 m/km (4.8 ft/mi). The northeastward deflection of the contours along the Upper Three Runs Creek indicates incisement of the sediments that constitute the aquifer by the creek.

Hydraulic characteristics of the Gordon are less variable than those noted in the Upper Three Runs aquifer. Selected parameters are given in Table 1.4-21. Hydraulic conductivity decreases downdip near well C-10 owing to poor sorting, finer grain size, and an increase in clay content.

Floridan - Dublin Aquifer System

Over most of the study area, the Meyers Branch confining system extends north of the Allendale confining system, hydraulically isolating the Floridan from the underlying Dublin and Dublin-Midville systems (see Figures 1.4-18 and 1.4-23). However, in a small region in the eastern part of the study area near well C-5, clay beds of the Meyers Branch confining system thin dramatically, leakance values increase, and the Floridan and Dublin Aquifer Systems are in overall hydraulic communication. In this region, the Floridan and Dublin Aquifer Systems coalesce to form the Floridan-Dublin Aquifer System (see Figure 1.4-23). Thick, continuous clay beds in the underlying Allendale confining system continue to hydrogeologically isolate the Midville and Floridan-Dublin Aquifer Systems.

The Floridan-Dublin Aquifer System is divided into three aquifers in the study area. In descending order, these include the Upper Three Runs, Gordon, and Crouch Branch aquifers separated by the Gordon and Crouch Branch confining units (see Figures 1.4-18 and 1.4-22). The Upper Three Runs and Gordon aquifers coalesce updip forming the Steed Pond aquifer. The Crouch Branch aquifer is continuous across the entire study area.

The Floridan-Dublin Aquifer System is defined by the hydrogeologic properties of sediments penetrated in well C-5 located north of the town of Barnwell. Here, the system is 171 meters (560 feet) thick and includes all sediments from the water-table to the top of the McQueen Branch confining unit. The Upper Three Runs aquifer is 44 meters (144 feet) thick and consists entirely of sand. The Gordon aquifer is 33 meters (108 feet) thick and consists of two sand beds that total 32 meters (105 feet). The Crouch Branch aquifer is 74 meters (244 feet) thick and consists of two sand beds that total 70 meters (230 feet).

Floridan - Midville Aquifer System

Northwest of Upper Three Runs Creek, the permeable beds that correspond to the Floridan and Dublin-Midville Aquifer Systems are often in hydrologic communication owing to the thin and laterally discontinuous character of the intervening clay and silty clay beds, to faulting that breaches the confining beds, and to erosion by the local stream systems that dissect the interval. Here, the Floridan and Dublin-Midville Aquifer Systems coalesce to form the Floridan - Midville Aquifer System (see Figures 1.4-18, -22, -23).

The Floridan-Midville Aquifer System is divided into three aquifers: in descending order, the Steed Pond aquifer, the Crouch Branch aquifer, and the McQueen Branch aquifer, separated by the Crouch Branch and McQueen Branch confining units. Both the Crouch Branch and the

McQueen Branch aquifers extend northwestward from the southern part of SRS. The Steed Pond aquifer is the updip hydrostratigraphic equivalent of the Gordon and Upper Three Runs aquifer units (see Figure 1.4-22). At the northern fringe of the study area, the Steed Pond and underlying Crouch Branch aquifers coalesce and a single, yet unnamed, aquifer unit is present.

The Floridan-Midville Aquifer System is defined by the hydrogeologic properties of the sediments penetrated in the GCB-1 type well located in the A/M Area in the northwest corner of SRS (see Figure 1.4-21). Near GCB-1, the system is 170 meters (557 feet) thick and includes all sediments from the water-table to the top of the Appleton confining system. The Steed Pond aquifer is 30 meters (97 feet) thick at the GCB-1 well and consists of 26 meters (86 feet) of sand in four beds. The Crouch Branch aquifer is 51 meters (167 feet) thick and consists of 42 meters (139 feet) of sand in four beds. It is overlain by the Crouch Branch confining unit, which is 25 meters (81 feet) thick and consists of 9 meters (31 feet) of clay in four beds. The McQueen Branch aquifer is 52 meters (169 feet) thick and consists of 45 meters (147 feet) of sand in three beds. The McQueen Branch confining unit is 13 meters (43 feet) thick and consists of 9 meters (28 feet) of clay in two beds.

Steed Pond Aquifer Unit

North of Upper Three Runs Creek where the Floridan - Midville Aquifer System is defined, the permeable beds that correspond to the Gordon and Upper Three Runs aquifers of the Floridan Aquifer System are only locally separated, owing to the thin and intermittent character of the intervening clay beds of the Gordon confining unit (Warley Hill Formation) and to erosion by the local stream systems that dissect the interval. Here, the aquifers coalesce to form the Steed Pond aquifer of the Floridan-Midville Aquifer System.

The Steed Pond aquifer is defined by hydrogeologic characteristics of sediments penetrated in well MSB-42 located in A/M Area in the northwest corner of SRS. The aquifer is 29.6 meters (97 feet) thick. Permeable beds consist mainly of subangular, coarse- and medium-grained, slightly gravelly, submature quartz sand and clayey sand (Ref. 118). Locally, the Steed Pond aquifer can be divided into zones. In A/M Area three zones are delineated, the "Lost Lake" zone, and the overlying "M Area" aquifer zones, separated by clay and clayey sand beds of the "green clay" confining zone (Ref. 119).

In A/M Area, water enters the subsurface through precipitation, and recharge into the "M-Area" aquifer zone occurs at the water-table by infiltration downward from the land surface. A groundwater divide exists in the A/M Area in which lateral groundwater flow is to the southeast towards Tims Branch and southwest towards Upper Three Runs Creek and the Savannah River floodplain. Groundwater also migrates downward and leaks through the "green clay" confining zone into the "Lost Lake" aquifer (Ref. 119). The "green clay" confining zone that underlies the "M-Area" aquifer zone is correlative with the Gordon confining unit south of Upper Three Runs Creek (Ref. 119).

Meyers Branch Confining System

The Meyers Branch confining system separates the Floridan Aquifer System from the underlying Dublin and Dublin-Midville Aquifer Systems (see Figures 1.4-18 and 1.4-22). North of the updip limit of the confining system, the Floridan and Dublin-Midville Aquifer Systems are in hydraulic communication and the aquifer systems coalesce to form the Floridan-Midville Aquifer System (Figure 1.4-23).

Sediments of the Meyers Branch confining system correspond to clay and interbedded sand of the uppermost Steel Creek Formation, and to clay and laminated shale of the Sawdust Landing/Lang Syne and Snapp Formations (see Figure 1.4-18). In the northwestern part of the study area, the sediments that form the Meyers Branch confining system are better sorted and less silty, with thinner clay interbeds. This is the updip limit of the Meyers Branch confining system (see Figure 1.4-22).

Crouch Branch Confining Unit

In the SRS area, the Meyers Branch confining system consists of a single hydrostratigraphic unit, the Crouch Branch confining unit, which includes several thick and relatively continuous (over several kilometers) clay beds. The Crouch Branch confining unit extends north of the updip limit of the Meyers Branch confining system where the clay thins and is locally absent and faulting observed in the region locally breaches the unit. Here, the Crouch Branch confining unit separates the Steed Pond aquifer unit from the underlying Crouch Branch aquifer unit. Downdip, generally south of the study area, the Meyers Branch confining system could be further subdivided into aquifer and confining units if this should prove useful for hydrogeologic characterization.

As indicated earlier (see Figure 1.4-20), a hydraulic-head difference persists across the Crouch Branch confining unit near SRS. Owing to deep incisement by the Savannah River and Upper Three Runs Creek into the sediments of the overlying Gordon aquifer, an upward hydraulic gradient (vertical-head reversal) persists across the Crouch Branch confining unit over a large area adjacent to the Savannah River floodplain and the Upper Three Runs Creek drainage system. This "head reversal" is an important aspect of the groundwater flow system near SRS and provides a natural means of protection from contamination of the lower aquifers.

The total thickness of the Crouch Branch confining unit where it constitutes the Meyers Branch confining system ranges from 17.4 to 56.1 meters (57 to 184 feet). Updip, the thickness of the Crouch Branch confining unit ranges from < 1 to 31.7 meters (3.3 to 104 feet). The confining unit dips approximately 5 m/km (16 ft/mi) to the southeast. The confining unit is comprised of the "upper" and "lower" confining zones, which are separated by a "middle sand" zone.

In general, the Crouch Branch confining unit contains two to seven clay to sandy clay beds separated by clayey sand and sand beds that are relatively continuous over distances of several kilometers. The clay beds in the confining unit are anomalously thin and fewer in number along a line that parallels the southwest-northeast trend of the Pen Branch and Steel Creek Faults and the northeast southwest trending Crackerneck Fault (Ref. 100). The reduced clay content near the faults suggests shoaling due to uplift along the faults during deposition of the Paleocene Black Mingo Group sediments.

In A/M Area, the Crouch Branch confining unit can often be divided into three zones: an "upper clay" confining zone is separated from the underlying "lower clay" confining zone by the "middle sand" aquifer zone. The "middle sand" aquifer zone consists of very poorly sorted sand and clayey silt of the Lang Syne/Sawdust Landing Formations. The "middle sand" aquifer zone has a flow direction that is predominantly south/southwest toward Upper Three Runs Creek (Ref. 120).

In places, especially in the northern part of A/M Area, "upper clay" confining zone is very thin or absent. Here, only the "lower clay" confining zone is capable of acting as a confining unit and the "middle sand" zone is considered part of the Steed Pond aquifer. Similarly, when the clay beds of the "lower clay" confining zone are very thin or absent, the "middle sand" aquifer zone is considered part of the Crouch Branch aquifer unit. This is the case in the far northeastern part of the study area.

The "lower clay" confining zone has been referred to as the lower Ellenton clay, the Ellenton clay, the Peedee clay, and the Ellenton/Peedee clay in previous SRS reports. It consists of the massive clay bed that caps the Steel Creek Formation. The zone is variable in total thickness and, based on 31 wells that penetrate the unit, ranges from 1.5 to 19 meters (5 to 62 feet) and averages 7.3 meters (24 feet) thick.

Dublin Aquifer System

The Dublin Aquifer System is present in the southeastern half of SRS and consists of one aquifer, the Crouch Branch aquifer. It is underlain by the Allendale confining system and overlain by the Meyers Branch confining system (see Figures 1.4-18 and 1.4-22). The updip limit of the Dublin Aquifer System in the study area corresponds to the updip limit of the Allendale confining system. North of this line, the Dublin-Midville Aquifer System is defined.

The thickness of the Dublin Aquifer System generally increases toward the south and ranges from approximately 53 to 88 meters (175 to 290 feet). The top of the unit dips 3.79 m/km (20 ft/mi) to the southeast. The unit thins to the east toward the Salkehatchie River and to the west toward Georgia. Near the updip limit of the system, thicknesses are variable and probably reflect the effects of movement along the Pen Branch Fault during deposition of the middle Black Creek clay.

The Dublin Aquifer System was defined and named by Clarke et al. (Ref. 121) for sediments penetrated by well 21-U4 drilled near the town of Dublin in Laurens County, Georgia. The upper part of the Dublin Aquifer System consists of fine to coarse sand and limestone of the lower Huber-Ellenton unit. Comparable stratigraphic units serve as confining beds in the SRS area and are considered part of the overlying Meyers Branch confining system. Clarke et al. (Ref. 21) noted that to the east near the Savannah River, clay in the upper part of the lower Huber-Ellenton unit forms a confining unit that separates an upper aquifer of Paleocene age from a lower aquifer of Late Cretaceous age. The upper aquifer of Clarke et al. (Ref. 121) is the Gordon aquifer as defined in the study, and their confining unit constitutes the Meyers Branch confining system of the SRS region. The lower part of the Dublin Aquifer System consists of alternating layers of clayey sand and clay of the Peedee-Providence unit.

Sediments typical of the Dublin Aquifer System are penetrated in the reference well P-22 (see Figure 1.4-21). The system consists of the well-sorted sand and clayey sand of the Black Creek Formation and the moderately sorted sand and interbedded sand and clay of the Steel Creek Formation. The aquifer is overlain by the clay beds that cap the Steel Creek Formation. These clay beds constitute the base of the Meyers Branch confining system.

The Dublin Aquifer System is 65 meters (213 ft) thick in well P-22; the top is at an elevation of -68 meters (-223 feet) msl and the bottom at -133 meters (-436 feet) msl. The Dublin includes five clay beds in this well.

In the southern part of the study area and farther south and east, the Dublin shows much lower values for hydraulic conductivity and transmissivity, probably due to the increase of fine-grained sediments toward the coast (Ref. 122).

Dublin - Midville Aquifer System

The Dublin-Midville Aquifer System underlies the central part of SRS. The system includes all the sediments in the Cretaceous Lumbee Group from the Middendorf Formation up to the sand beds in the lower part of the Steel Creek Formation (see Figure 1.4-18). The system is overlain by the Meyers Branch confining system and underlain by the indurated clayey silty sand and silty clay of the Appleton confining system. The updip limit of the system is established at the updip pinchout of the overlying Meyers Branch confining system (see Figure 1.4-22). The downdip limit of the Dublin-Midville is where the Allendale becomes an effective confining system (see Figure 1.4-22). The Dublin-Midville and the updip Floridan-Midville Aquifer Systems were referred to as the Tuscaloosa aquifer by Siple (Ref. 123).

The thickness of the Dublin-Midville Aquifer System ranges from approximately 76 to 168 meters (250 to 550 feet). The dip of the upper surface of the system is about 3.8 m/km (20 ft/mi) to the southeast. Near the downdip limit of the system, thicknesses are variable and probably reflect the effects of movement along the Pen Branch Fault. Shoaling along the fault trace resulted in a relative increase in the thickness of the aquifers at the expense of the intervening confining unit.

The Dublin-Midville Aquifer System includes two aquifer units, the McQueen Branch aquifer, and the Crouch Branch aquifer, separated by the McQueen Branch confining unit. The two aquifers can be traced northward, where they continue to be an integral part of the Floridan-Midville Aquifer System and southward where they constitute the aquifer units of the Midville and Dublin Aquifer Systems, respectively.

The Dublin-Midville Aquifer System is defined at the type well P-27. Here, the system is 153 meters (505 feet) thick and occurs from -25 meters (-82 feet) msl to -179 meters (-587 feet) msl. It consists of medium- to very coarse-grained, silty sand of the Middendorf Formation and clayey, fine to medium sand and silty clay beds of the Black Creek Formation (Ref. 118).

The system includes a thick clay bed, occurring from -100 meters (-329 feet) msl to -117 meters (-384 feet) msl, which constitutes the McQueen Branch confining unit.

A regional potentiometric surface map prepared by Siple (Ref. 123) for his "Tuscaloosa aquifer," indicates that the Savannah River has breached the Cretaceous sediments and is a regional discharge area for the Floridan-Midville Aquifer System, the Dublin-Midville Aquifer System, and the updip part of both the Dublin and Midville Aquifer Systems (Ref. 124). The Savannah River, therefore, represents a no-flow boundary preventing the groundwater in these aquifer systems from flowing southward into Georgia.

Crouch Branch Aquifer Unit

The Crouch Branch aquifer constitutes the Dublin Aquifer System in the southern part of the study area. Farther south, the Dublin can be subdivided into several aquifers and confining units. In the central part of the study area, the Crouch Branch aquifer is the uppermost of the two aquifers that constitute the Dublin-Midville Aquifer System. Farther north in the northwestern part of SRS and north of the site, the Crouch Branch aquifer is the middle aquifer of the three aquifers that constitute the Floridan-Midville Aquifer System.

The Crouch Branch aquifer is overlain by the Crouch Branch confining unit and is underlain by the McQueen Branch confining unit. It persists throughout the northern part of the study area, but near the updip limit of the Coastal Plain sedimentary clastic wedge, the Crouch Branch confining unit ceases to be effective and the Crouch Branch aquifer coalesces with the Steed Pond aquifer.

The Crouch Branch aquifer ranges in thickness from about 30 to 107 meters (100 to 350 feet). Thickness of the unit is variable near the updip limit of the Dublin Aquifer System where sedimentation was affected by movement along the Pen Branch Fault. The reduced clay content in this vicinity suggests shoaling due to uplift along the fault during Late Cretaceous and Paleocene time, resulting in the deposition of increased quantities of shallow-water, coarse-grained clastics along the crest of the fault trace. The sandy beds act hydrogeologically as part of the Crouch Branch aquifer, resulting in fewer and thinner, less persistent clay beds in the overlying and underlying confining units.

The Crouch Branch aquifer thins dramatically in the eastern part of the study area at the same general location where the underlying McQueen Branch confining unit and the overlying Crouch Branch confining unit thicken at the expense of Crouch Branch sand. Clay beds in the Crouch Branch aquifer generally thicken in the same area and constitute as much as 33 percent of the unit at the well C-6 (see Figure 1.4-21).

Sediments of the Crouch Branch aquifer are chiefly sand, muddy sand, and slightly gravelly sand intercalated with thin, discontinuous layers of sandy clay and sandy mud. Hydraulic conductivity of the Crouch Branch aquifer, determined from eleven pumping tests by Siple (Ref. 123) and from analyses made by GeoTrans (Ref. 125), ranges from 8.5 to 69 m/day (28 to 227 ft/day). Comparatively high hydraulic conductivity occurs in a northeast-southwest trending region connecting D Area, Central Shops, and R Area and defines a "high permeability" zone in the aquifer. Here, hydraulic conductivities range from 36 to 69 m/day (117 to 227 ft/day). The "high permeability" zone parallels the trace of the Pen Branch Fault, and reflects changing depositional environments in response to movement along the fault as described above. South of the trace of the Pen Branch Fault, hydraulic conductivity for the aquifer reflects the return to a deeper water shelf/deltaic depositional regime. A potentiometric map for the Crouch Branch Aquifer is presented in Figure 1.4-26.

Allendale Confining System

The Allendale confining system is present in the southeastern half of the study area and separates the Midville Aquifer System from the overlying Dublin Aquifer System (see Figure 1.4-18). In the study area, the Allendale confining system consists of a single unit, the McQueen Branch confining unit. The confining system is correlative with the unnamed confining unit that separates the Middendorf and Black Creek aquifers of Aucott et al. (Ref. 122) and with the Black Creek-Cusseta confining unit of Clark et al. (Ref. 121). The system dips approximately 6.7 m/km (27 ft/mi) to the southeast and thickens uniformly from about 15.2 meters (50 feet) at the updip limit to about 61 meters near the eastern boundary of the study area. The rate of thickening is greater in the east than in the west. The updip limit of this confining system is established where pronounced thinning occurs parallel to the Pen Branch Fault.

Sediments of the Allendale confining system are fine grained and consist of clayey, silty sand, clay, and silty clay and micritic clay beds that constitute the middle third of the Black Creek Formation. North of the updip limit of the confining system, where the McQueen Branch confining unit is part of the Dublin-Midville Aquifer System, the section consists of coarser-grained, clayey, silty sand and clay beds.

McQueen Branch Confining Unit

The McQueen Branch confining unit is defined by the hydrogeologic properties of the sediments penetrated in well P-27 (see Figure 1.4-21). At its type-well location, the McQueen Branch confining unit is 17 meters (55 feet) thick, and is present from -100 to -117 meters (-329 to –384 feet) msl. Total clay thickness is 14 meters (45 feet) in three beds, which is 82% of the total thickness of the unit, with a leakance coefficient of 3.14×10^{-6} m/day (1.03×10^{-5} ft/day). The confining unit in well P-27 consists of the interbedded, silty, often sandy clay and sand beds that constitute the middle third of the Black Creek Formation.

The clay beds tend to be anomalously thin along a line that parallels the southwest-northeast trend of the Pen Branch Fault and the north-south trend of the Atta Fault (Ref. 126). The reduced clay content in these areas suggests shoaling due to uplift along the faults during Upper Black Creek-Steel Creek time.

Midville Aquifer System

The Midville Aquifer System is present in the southern half of the study area; it overlies the Appleton confining system and is succeeded by the Allendale confining system. In the study area, the Midville Aquifer System consists of one aquifer, the McQueen Branch aquifer unit.

South of well C-10 (see Figure 1.4-21), the system may warrant further subdivision into several aquifers and confining units. Thickness of the unit ranges from 71 meters (232 feet) at well P-21 to 103 meters (339 feet) at well C-10. Variation in the thickness of the unit, as well as the updip limit of the system, results from variation in the thickness and persistence of clay beds in the overlying Allendale confining system. Near the Pen Branch Fault, contemporaneous movement on the fault may have resulted in shoaling in the depositional environment, which is manifested in a thickening of the sands associated with the Midville Aquifer System. The upper surface of the aquifer system dips approximately 4.73 m/km (25 ft/mi) to the southeast across the study area.

The Midville Aquifer System was defined and named by Clarke et al. (Ref. 121) for the hydrogeologic properties of the sediments penetrated in well 28-X1, near the town of Midville in Burke County, Georgia. Here, the upper part of the aquifer system consists of fine to medium sand of the lower part of the Black Creek-Cusseta unit. The Midville is comparable to the lower portion of the Chattahoochee River aquifer of Miller and Renken (Ref. 104) and correlative with the Middendorf aquifer of Aucott and Sperian (Ref. 127).

McQueen Branch Aquifer Unit

The McQueen Branch aquifer unit occurs beneath the entire study area. It thickens from the northwest to the southeast and ranges from 36 meters (118 feet) at well AIK-858 to 103 meters (339 feet) at well C-10 to the south. Locally, thicknesses are greater along the trace of the Pen Branch Fault because of the absence and/or thinning of clay beds that compose the overlying McQueen Branch confining unit. The upper surface of the McQueen Branch dips approximately 4.7 m/km (25 ft/mi) to the southeast.

The McQueen Branch aquifer unit is defined for the hydrogeologic properties of sediments penetrated by well P-27 near the center of the study area. Here, it is 62 meters (203 feet) thick and occurs from -117 to -180 meters (-384 to –587 feet) msl. It contains 56 meters (183 feet) of sand in four beds, (which is 90% of the total thickness of the unit). The aquifer consists of silty sand of the Middendorf Formation and clayey sand and silty clay of the lower one-third of the Black Creek Formation (Ref. 118). Typically, a clay bed or several clay beds that cap the Middendorf Formation are present in the aquifer. These clay beds locally divide the aquifer into two aquifer zones.

Eight pumping tests of the McQueen Branch aquifer were made in F and H Areas, in the central part of the study area (Ref. 123). Hydraulic-conductivity values ranged from 16 to 64 m/day (53 to 210 ft/day) and averaged 36 m/day (18 ft/day). Three pumping tests of the aquifer were reported by GeoTrans: two in F Area and one in L Area (Ref. 128). Hydraulic conductivity ranged from 13 to 88 m/day (41 to 290 ft/day) in F Area and was 28 m/day (93 ft/day) in L Area.

Appleton Confining System

The Appleton confining system is the lowermost confining system of the Southeastern Coastal Plain hydrogeologic province and separates the province from the underlying Piedmont hydrogeologic province. It is equivalent to the Black Warrior River aquifer of Miller and Renken

(1988) and to the basal unnamed confining unit of Aucott et al. (Ref. 122). The confining system is essentially saprolite of the Paleozoic and Mesozoic basement rocks and indurated, silty and sandy clay beds, silty clayey sand and sand beds of the Cretaceous Cape Fear Formation. Thickness of saprolite ranges from 2 to 14 meters (6 to 47 feet), reflecting the degree of weathering on the basement unconformity prior to deposition of the Cape Fear terrigenous clastics. Thickness of saprolite determined from the Deep Rock Borings study (DRB wells) ranges from 9 to 30 meters (30 to 97 feet) and averages 12 meters (40 feet) in wells DRB-1 to DRB-7 (Ref. 128). In the northern part of the study area, the Cape Fear Formation pinches out and the Appleton consists solely of saprolite.

Some variability in thickness is noted along the trace of the Pen Branch Fault. It dips at about 5.9 m/km (31 ft/mi) to the southeast and thickens from 4.6 meters (15 feet) in well C-2 near the north end of the study area to 22 meters (72.2 feet) in well C-10 in the south. Sediments of the confining system do not crop out in the study area. Thinning of the Appleton confining system in well PBF-2 (see Figure 1.4-21) is probably a result of truncation of the section by the Pen Branch Fault.

The confining system consists of a single confining unit throughout the study area. Toward the coast, however, the Appleton confining system thickens considerably and includes several aquifers (Ref. 121). The aquifers included in the confining system in the downdip region are poorly defined because few wells penetrate them. They are potentially water producing but the depth and generally poor quality of water in the aquifers probably precludes their utilization in the foreseeable future (Ref. 122). The Appleton confining system includes no aquifer units or zones in the northern and central parts of the study area.

Fine- to coarse-grained sand beds, often very silty and clayey, occur in the upper part of the Cape Fear Formation in the southern part of the study area. The sand appears to be in communication with sand of the overlying McQueen Branch Aquifer System and is included with that unit.

HYDROGEOLOGY OF THE PIEDMONT PROVINCE

The basement complex, designated the Piedmont hydrogeologic province in this report, consists of Paleozoic crystalline rocks, and consolidated to semiconsolidated Upper Triassic sedimentary rocks of the Dunbarton basin. All have low permeability (Ref. 129). The hydrogeology of the province was studied intensively at SRS to assess the safety and feasibility of storing radioactive waste in these rocks (Ref. 130-134). The upper surface of the province dips approximately 11 m/km (36 ft/mi) to the southeast. Origins of the crystalline and sedimentary basement rocks are different, but their hydraulic properties are similar. The rocks are massive, dense, and practically impermeable except where fracture openings are encountered. Water quality in these units is also similar. Both contain water with high alkalinity and high levels of calcium, sodium, sulfate, and chloride. The low aquifer permeability and poor water quality in the Paleozoic and Triassic rocks render them undesirable for water supply in the study area.

1.4.2.3 Area Hydrogeology (Selected Savannah River Site Operations Areas)

The following section focuses on the general hydrogeology of selected operations areas at SRS. The operations areas selected are those that include facilities that require a SAR. The most detailed information for any facility is discussed in its facility-specific SAR.

In general, updated hydrogeological data and descriptions of facility-specific hydrostratigraphy are included in reports of field investigations at or near the facility of interest. These reports may include Resource Conservation and Recovery Act (RCRA) Part B Applications, RCRA Facility Investigations/Remedial Investigations or Baseline Risk Assessments, environmental assessments of various kinds, or other field investigation reports. Field activities at the various site facilities are reported in the annual SRS Environmental Report (Ref. 20).

AREA HYDROGEOLOGICAL CHARACTERISTICS - GENERAL SEPARATIONS AREAS

The General Separations Area as defined herein includes F Area, E Area, H Area, S Area, and Z Area. In the past, the focus of facilities in this area has been on chemical separations; changes in the site mission have impacted operations in the General Separations Area, including the construction and startup of Tritium Facilities and various waste management facilities (DWPF, E-Area Vaults and the CIF).Water Usage

Water usage at the F Area/E Area facilities varies from year to year and is a function of increased or decreased site activities. Current data for pumping in F Area/E Area is reported in the SRS Annual Environmental Report (Ref. 20). To date, operation of production water wells has not caused subsidence of the F-Canyon foundation nor influenced potential contaminant flow paths in the post-Cretaceous aquifers.

Hydrogeologic Setting

The General Separations Area sits above a water-table ridge, defined on the south by Fourmile Branch and on the north and west by Upper Three Runs Creek (see Figure 1.4-27). The ridge is dissected on the northern flank by Crouch Branch (between E Area and H Area) and McQueen Branch (east of Z Area). Thus, the facilities lie above minor groundwater divides; flow at the water-table is generally away from the facilities and toward the nearest surface water (Ref. 100). The majority of water that reaches the water-table beneath the General Separations Area is discharged into either Upper Three Runs Creek (or its tributaries) or Fourmile Branch.

In general, there is very limited downward migration of groundwater across the Meyers Branch confining system beneath the General Separations Area. Therefore, the hydrostratigraphic units linked to General Separations Area operations are the Upper Three Runs Aquifer (the water-table aquifer), the Gordon confining unit, and the Gordon aquifer unit. A discussion of the hydraulic properties and hydraulic gradients for these units is included above under the "Southeastern Coastal Plain Hydrogeologic Province" section. This discussion is pertinent because only limited data are available from outside the General Separations Area; thus, the data can be used to characterize conditions beneath the General Separations Area.

Hydraulic conductivity values for the Upper Three Runs, Gordon, and Steed pond aquifers are presented in Table 1.4-22. Typically, data from short-duration single well tests and slug tests are the best representative of the true hydraulic parameters for a hydrogeologic unit (Ref. 100). If available, these data should be used for calculating groundwater flow velocity, contaminant migration, and other pertinent hydraulic properties.

1.4.2.4 Groundwater Chemistry

REGIONAL GROUNDWATER CHEMISTRY

SRS groundwater quality samples are collected quarterly, and the data, as well as interpreted results, are presented in the Annual SRS Environmental Report (Ref. 20). For illustrative purposes, Table 1.4-23 presents a set of water analyses from sources within SRS and vicinity. The location of industrial and municipal groundwater users near SRS are shown in Figure 1.4-29. The pumpages are tabulated in Table 1.4-24.

An investigation of the geochemistry of the water residing in the principal aquifer units at SRS was undertaken as part of the Baseline Hydrologic Investigation (Ref. 103). This study investigated the effects of the mineralogy of the aquifer materials, source of the water, and the effect of biological activity on the evolution and chemistry of the groundwater. Groundwater chemistry and geologic data utilized for this study were obtained from monitoring wells and core samples collected during drilling activities. The majority of the ensuing discussions were adapted directly from this report.

The primary source of groundwater at the SRS is precipitation. As the water migrates away from the source or recharge area, it experiences a decrease of pH and an increase in total dissolved solids. In addition, the overall chemistry changes as it encounters different aquifer material. The primary recharge areas for the deeper aquifers in the SRS vicinity are located near the fall line or Coastal Plain onlap. From there, the groundwater migrates in a general southwest direction. The extent to which the local discharge and recharge areas impact the groundwater chemistry is dependent upon the depth of a particular aquifer system below ground surface and the overall aquifer material. Recharge for the water-table aquifers is derived from local, recent precipitation at the site as evidenced by elevated amounts of short-lived isotopes such as tritium, and the ionic composition of the groundwater.

According to Strom and Kaback (Ref. 137), tritium levels in local precipitation are in excess of the normal background levels for the Northern Hemisphere. Washout from the atmosphere during periods of precipitation has elevated the concentration of rainfall tritium to where pre- and post-1954 rainfall-derived water can clearly be distinguished in groundwater. The year 1954 is significant in that it represents the beginning of Savannah River Plant facility operations.

The impact of rainfall-derived tritium on the groundwater is observed in groundwater resident at depths of less than 61 meters (200 feet).

The ionic composition of the groundwater also clearly reflects a meteoric origin of the water. Chemical data from rainwater collected near SRS exhibit approximately the same ratio of sodium to chlorine as that in seawater, which is a principal source of atmospheric salts, but higher levels of sulfate and calcium. These latter constituents are commonly contributed to the atmosphere over landmasses by natural biological processes and industrial emissions.

Aquifer Materials

Groundwater principally resides in the pore spaces of the sandy aquifers. In these aquifers, quartz is the dominant mineral. Despite its abundance, its affect on overall water chemistry is negligible due to the low reactivity of this quartz (except in cases of extremely basic pH). The minerals that potentially impact the chemistry of the groundwater are less abundant. Minerals identified by x-ray diffraction and x-ray fluorescence data include feldspars and a host of phyllosilicates (i.e., clays and micas). Other non-silicate minerals such as pyrite, gypsum, barite, calcite, and hematite were also identified, but these are relatively sparse and have little impact on the overall groundwater chemistry. Clay minerals present include kaolinite, smectites and in minor amounts, illite.

Groundwater Chemistry (Hydrochemical Facies)

The evolution of groundwater in the Coastal Plain sediments can be defined from the source or recharge areas down the hydraulic gradient within the aquifer. Although groundwaters at SRS are very dilute, they show significant changes in the levels of dissolved oxygen, redox potential, dissolved trace constituents, and in the major cations and anions present. The variations in these major constituents are useful in delineating the chemical reactions, which occur during the chemical development of the groundwater.

On the northern edge of the site where there is a single aquifer system (see Figure 1.4-23), the waters are of very low total dissolved solids (less than 20 mg/L). They contain high concentrations of dissolved oxygen, have pH lower than 6.0, and are classified as mixed water types (i.e., there are no predominant cations or anions in the water). The confining units that separate the aquifers are only of local extent and the hydraulic gradient is downward from the Tertiary formations into the underlying Cretaceous formations over much of this portion of the site. The Cretaceous aquifer receives recharge from Tertiary units where the confining units are thin or absent.

South of this region, where two or more aquifer systems are present (see Figure 1.4-23), the waters become geochemically distinctive because of bio-geochemical and geochemical interaction with the water and the sediments and buried organic materials. Water samples in both

of the aquifers are shown to have a predominance of calcium-bicarbonate. The presence of calcium-bicarbonate is most frequently attributed to the dissolution of $CaCO_3$. Several reaction mechanisms are known to exist for the dissolution reactions. The dissolution by weak carbonic acid;

$$CaCO_3 + H_2CO_3 \longrightarrow Ca^{2+} + 2HCO_3^- \qquad \text{(Eq. 1.4-2)}$$

produces two bicarbonate ions per calcium ion whereas the hydrolysis reaction produces a single bicarbonate plus a hydroxyl ion.

$$CaCO_3 + H_2O \text{ ---> } Ca^{2+} + HCO_3^- + OH^- \qquad \text{(Eq. 1.4-3)}$$

In either case, equal amounts of alkalinity are produced by the reaction so that the bicarbonate concentration calculated from alkalinity data in this study are not useful indicators to distinguish the reaction mechanisms. It is probable that both reactions contribute in the Tertiary aquifers. There have not been sufficient ^{13}C isotopic data obtained on these aquifer units or direct measurement of dissolved inorganic carbon to generalize at the present time.

The samples from monitoring wells screened in the Tertiary section at the P-19 well (see Figure 1.4-21) site cluster are anomalous in their water chemistry because they are low in total dissolved solids and show no evidence of having had opportunity to react with carbonates (low alkalinity and moderate pH). This is true of the P-19 wells screened in the Upper Three Runs aquifer and Gordon aquifer. In addition limestones, marls, and clay units are conspicuously absent from the Tertiary section at this locality (Ref. 137) and, therefore, high vertical permeabilities are expected.

The Cretaceous or deeper aquifers (Midville, Dublin, and or Dublin-Midville) south of Upper Three Runs Creek have a somewhat more complex chemistry. Examination of Piper diagrams for these units shows a marked evolution from sulfate-rich waters at low total dissolved solids (TDS) toward bicarbonate-rich waters at higher TDS. The evolution toward calcium-rich waters is not as pronounced as in the Tertiary units. Alkalis (Na+K) are major contributors to the cation compositions, and the waters would be classified as mixed water types or $Na+K\text{-}HCO_3$ waters by Back's classification system. The reaction pathways toward these compositions are complex and not well understood at present.

The calcium in these waters may be derived from several sources, including dissolution of gypsum from confining beds such as the Rhems (Ellenton) Formation, which is the downdip equivalent of the Lang Syne/Sawdust Landing Formation (Ref. 115), the dissolution of calcite or calcium plagioclase, or displacement of calcium by potassium in cation exchange reactions. The alkalis in the Cretaceous aquifer waters are primarily derived from the breakdown of silicate minerals including feldspars, mica, and various clay minerals including illite.

There is no consistent trend in the proportion of potassium to sodium in the waters as total dissolved solids increases. Because potassium is usually the most tightly bound ion in cation exchange reactions, its relative abundance in the samples from McQueen Branch and Crouch Branch aquifer units suggests that cation exchange has not played a dominant role in the evolution of these waters. The exceptions are the samples from well C-10 (see Figure 1.4-21), where sodium is clearly the dominant cation. In this down-gradient locality south of SRS, cation exchange processes have led to water conditions comparable to those formed by exchange processes observed in other regions of the South Carolina Coastal Plain (Ref. 122).

Increases in the HCO_3^- concentration are apparently largely through the microbial oxidation of lignite within the aquifers. The ^{13}C signatures of the water are typically light; in the range of

-0‰ to -25‰ . Usually, these light values indicate an organic source of carbon rather than the dissolution of limestone or other inorganic ion source.

Dissolved oxygen is less than 0.1 mg/L for most of the samples from the Dublin-Midville Aquifer System. From Upper Three Runs Creek southward, the aquifers in this system are anaerobic and contain abundant dissolved iron. The iron content in these aquifers is undesirably high, usually between 1 and 5 mg/L. The anaerobic conditions allow the dissolved iron to remain in the ferrous form but have not become reducing to the extent that sulfate has been reduced to the sulfide form.

Chapelle and Loveley (Ref. 138) have described a high-iron groundwater zone in the Middendorf Aquifer (comparable to McQueen Branch), approximately 40 km (124 miles) wide, that extends across South Carolina from SRS to North Carolina approximately paralleling the Fall Line. This high-iron zone is inferred to result from the reduction of iron oxyhydroxide grain coatings by bacteria during the oxidation of organic matter within the confined zones of the aquifer. According to Strom and Kaback (Ref. 137), the activity of the iron-reducing bacteria may inhibit the activity of sulfate-reducing bacteria. Sulfate reduction begins further downgradient after the more easily oxidized organics have been consumed.

AREA GROUNDWATER CHEMISTRY

The following sections focus on the general groundwater chemistry and groundwater use of selected operations areas at SRS. The operations areas selected are those that include facilities that require a SAR. The most detailed information for any facility is discussed in its facility-specific SAR.

Water Chemistry - F and E Areas

A monitoring well network consisting of over 100 wells has been installed to monitor groundwater quality in F Area. Well construction information, including maps showing well location, is provided in the Environmental Protection Department's quarterly well inventory. The most recent sampling information is presented in the quarterly SRS Groundwater Monitoring Report and the SRS Annual Environmental Report (Ref. 20).

The potential local groundwater recharge zone closest to F Canyon is the upland area with downward vertical gradients just to the southeast of F Area. Recharge areas for the Cretaceous aquifers are located outside of the SRS boundary. Table 1.4-25 provides radiological and chemical analyses data from a part of a 16-well monitoring network located near accessible expansion joints beside Building 221-F.

Construction of the F-Area facilities has had no effect on groundwater recharge areas; groundwater had no effect on construction activities.

Water Chemistry - H, S, and Z Areas

The results of the groundwater monitoring program, including background levels and flagging criteria, are discussed in the SRS Annual Environmental Report (Ref. 20).

The potential local groundwater recharge zone closest to H Area is the upland area with downward vertical gradients just to the southeast of H Area. Recharge areas for the Cretaceous aquifers are located outside of the SRS boundary.

Construction of facilities in the H, S, and Z Areas has had no effect on groundwater recharge areas. Groundwater has not affected construction activities. No groundwater injections or withdrawals that would affect the underlying aquifers are planned for this site.